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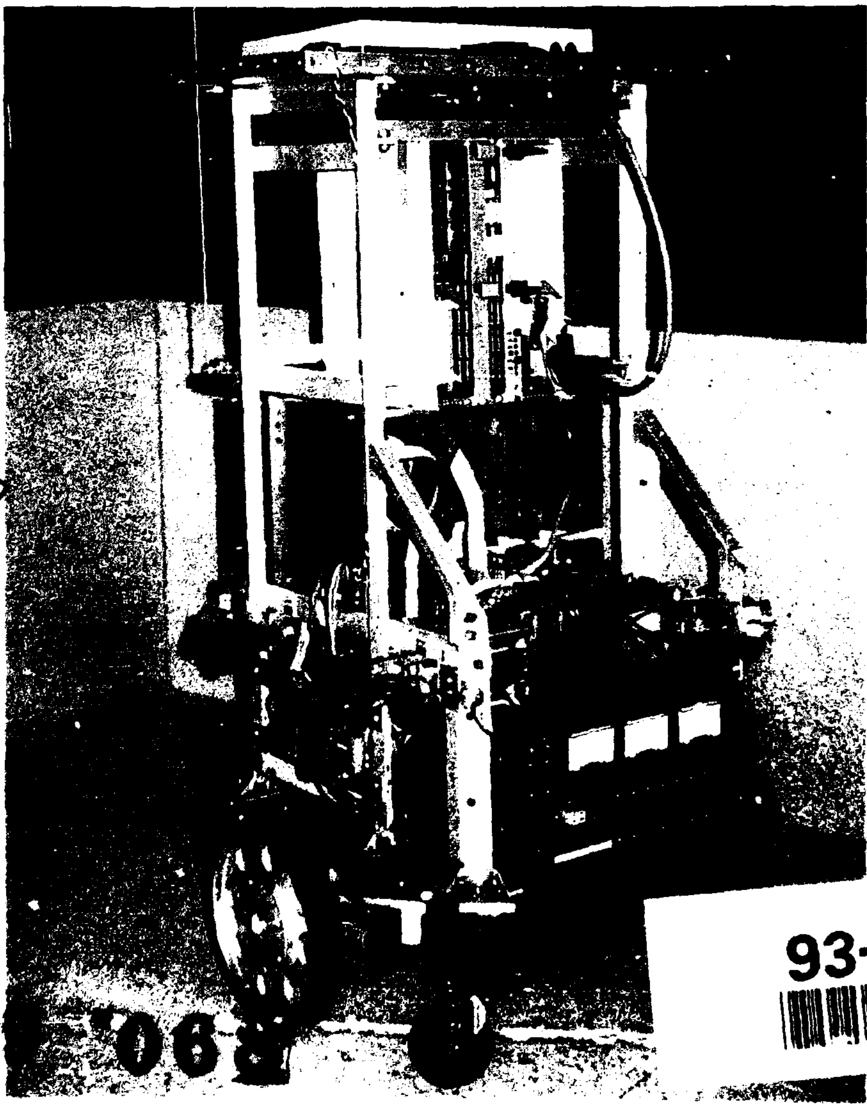

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONRASIA, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large. It is available free of charge to approved members of the DOD scientific community. Send written request describing DOD affiliation to: Director, Office of Naval Research, Asian Office, Unit 45002, APO AP 96337-0007.

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Cover: Yamabico-11, the robot designed by Prof. Yutaka Kanayama, Naval Postgraduate School (see his article on page 107).

SIBRIEFs

Scientific Information Briefs

UPDATE ON AN UNMANNED HELICOPTER WITH FUZZY CONTROLLER

Last year I wrote about helicopter flight control based on a fuzzy logic developed by Prof. M. Sugeno at the Tokyo Institute of Technology [D.K. Kahaner and D.G. Schwartz, "Fuzzy helicopter flight control," *Scientific Information Bulletin* 16(4), 13-15 (1991)]. Since then Prof. Sugeno has sent me some additional written material as well as several striking photos of the model helicopter in operation.

The project is to develop an unmanned helicopter for operation over water that would respond to simple voice controls such as "hover," "land," "fly straight," "turn left," etc.

The current system has 13 measured inputs, 3 angles of rotation--roll, pitch, and yaw--3 angular velocities, velocities and accelerations along three axes, and altitude. Two additional state variables (horizontal position) cannot be measured. Sensors are made by Tokimec; angles, angular velocities, and accelerations are measured by TMOS-1000, the altitude by an ultrasonic wave sensor, and velocities by a microwave Doppler interference sensor. Global positioning information has not yet been incorporated, but plans are to include this when it becomes available here in Japan.

There are four outputs that are the four control inputs to the helicopter such as elevator adjustment for forward-backward movement, aileron adjustment for left-right movement, throttle adjustment for up-down movement, and rudder adjustment for nose direction.

The helicopter used in Sugeno's experiments is a Yamaha R-50, about 3.5 meters long with a 90-kg payload and a 98-cc engine.

The controller is based on fuzzy logic and is installed in a 16-bit microprocessor with a fuzzy inference engine built by Omron.

The most interesting aspect of the system is its hierarchical structure. At the top level is a navigator system that receives operator's instructions (hover, land, etc.) along with the present flight states of the helicopter from the sensors. The navigator provides as output both trim information (an equilibrium position of the helicopter's attitude) and the desired values of the control inputs. Both sets of information are input to the lower level, the stabilizer level, which is a servo system with the trim as its reference signal. The stabilizer consists of blocks corresponding to its flight modes, e.g., a sideways flight block, forward flight block, hover flight block, etc. Each block consists of four modules corresponding to the four control inputs (elevator, aileron, rudder, and throttle).

This kind of hierarchical and modular structure simplifies the acquisition of control rules as well as the controller design. It is also natural as a pilot recognizes that his own ability at control is also hierarchical. To improve stability and the control dynamics, there is also built-in feed-forward control action.

The navigator has two subsystems: a major one outputs standard trim and a minor one compensates it. The major subsystem has rules such as "If flight mode is HOVER and flight state is FORWARD then standard trim is sTRIM." The latter is a four-tuple (P,E,R,A), which is the reference signals of the pitch angle, roll angle, and the offsets of the elevator and aileron. Since true trim can deviate from the standard, it must be compensated, given by TRIM = sTRIM + cTRIM. cTRIM = pcTRIM + dcTRIM, where pcTRIM is the prior cTRIM and dcTRIM is output of the minor system. The minor subsystem has rules as follows:

If X is + and dX is + then dcTRIM is v1
If X is + and dx is 0 then dcTRIM is v2
.
.
If Y is - and dY is - then dcTRIM is v9

(Here X, Y are longitudinal and lateral velocity and dX, dY are corresponding accelerations.)

The control rules in the stabilizer were obtained firstly by interviewing pilots and then tested and modified experimentally with a helicopter flight simulator at Kawasaki Heavy Industries. In total 54 rules were developed based on pilot knowledge. Such knowledge was formulated in statements like

"If the body pitches then control the elevator in reverse"
"If the body moves sideways, then control the aileron in reverse"

Each developed rule has two inputs and one output. Inputs are linguistic variables (positive, negative, zero). For example, some elevator rules are

If EP is + and dP is + then Eo=a1
If EP is + and dP is) then Eo=a2

etc. Here EP=Pr-P (previous minus current pitch angle), dP is pitch angular velocity, and Eo is elevator output of the stabilizer.

Currently, the helicopter can support the following flight modes: hovering, hovering turn, forward/rearward flight, left/rightward flight, and stop. Other flight modes are in progress: takeoff, acceleration/deceleration, left/right turn, climb/descent, and landing.-- *David K. Kahaner, ONRASIA*

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JANUARY 1992 WAVELET SEMINAR

The Audio Visual Information Research Group (AVIRG), or the Shichokaku Joho Kenkyu Kai, sponsors monthly seminars on a variety of scientific and engineering topics at the School of Engineering, Tokyo University, Hongo Branch. Attendance is open to the general public; there are no fees or no membership requirements. Twice a year one of the monthly seminars covers a subject in great detail in which a number of experts are invited to present a series of lectures. This particular seminar on wavelets was chosen to be one of the semi-annual big events for 1992. The topic was suggested by Hideki Kawahara of NTT Basic Research Laboratories.

The first lecture, "Wavelets (Theory)," was given by Masaaki Sato, from the ATR Auditory and Visual Perception Laboratories. Sato began his lecture with the astonishing statement that he does not understand the sudden and, perhaps, unjustifiably high interest in wavelets; none of the ideas associated with wavelets is entirely new, and none of the applications has produced results that are better than or cannot be produced by more conventional methods. He half-jokingly suggested that perhaps we had all gathered to check up on what is happening on wavelets and are anxious lest we miss out on a potentially lucrative or imaginative application of wavelets. Perhaps so, as it appeared that the majority of the audience consisted of industrial scientists from large, corporate, basic research laboratories, e.g. NEC, NTT, Hitachi, IBM, HP.

The basic properties of wavelets such as their generation from a mother function using dilations and translations were introduced. Sato's presentation on the Fourier-wavelet analogy was clear and insightful. The time-frequency limitations of the Fourier methods were noted. In Fourier methods, the size of the sampling window is fixed, whereas in the wavelet method the window size can be set to short windows at high frequencies and long windows at low frequencies. The flexibility in choosing the sampling window size is a nice property; however, Sato favored the idea that much of the hoopla over wavelet expansions arises from the overcompleteness property of wavelet bases, a desirable but not particularly unique property. He discussed and later reiterated that Prof. Ogawa and his colleagues at To-ko-dai have been studying the role of overcompleteness properties and their applications to noise suppression in signal analysis. Discussion on the wavelet transform and its invertibility properties followed what has been published in the literature. Work on wavelets and Cantor sets by Arneodo, Grasseau, and Holschneider (1988) was briefly mentioned as time ran out. For further information, please contact:

Masaaki Sato
ATR Auditory and Visual
Perception Laboratories
Sanpeidani, Inuidani, Seika-cho
Soraku-gun, Kyoto 619-02, Japan

The second lecture, "Signal Processing of Human Voice Data," was given by Toshio Irino, NTT Basic Research Laboratories. His talk was strikingly different in tone from that of Kawahara given at the Society for Industrial and Applied Mathematics (SIAM) wavelet seminars late last year. Irino's frankness was refreshing and should be commended. He discussed through demos how his initial optimism regarding possible applications of wavelet-based techniques to voice compression and reconstruction was overly naive at best and entirely off-track at worst. It appears, at least for now, that results from his wavelet-based processing techniques cannot even equal those from more conventional methods. Perhaps I am wrong, but Irino's demo seemed to be the same as that given by Kawahara. It struck me as peculiar that two coauthors and joint researchers could set such different outlooks (optimistic versus pessimistic) on the future of their wavelet-based voice processing work. For further information, please contact:

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Mutsumi Ohta (NEC C&C System Research Laboratories) gave the third lecture titled "Two-Dimensional Image Processing." He presented a brief sketch of the history of two-dimensional image processing to give the audience perspective on the evolution as well as current status of wavelets and their applications. He distributed a time chart comparing and pointing out the relationships between five processing methods: transform coding, subband

coding, pyramid coding, wavelet, and pattern recognition. Ohta believes that the conjugate quadrature filter (CQF) is the first method that can be called wavelet-like. He noted that Barnel's assumptions are similar to those of Mallat and Daubechies, but the latter have added conditions such as admissibility for mathematical rigor. Unfortunately, Ohta had incorrectly anticipated that Sato would outline the concept of multiresolution analysis, so an improvised summary was given.

Ohta noted that one of the more promising areas for applying wavelet techniques is in two-dimensional image processing, with time as a third dimension. Clean processing of rapidly moving objects is very difficult using discrete cosine transform (DCT) techniques. It is difficult to prevent severe blurring of the images; this blurring has been given many nicknames, such as the "mosquito effect" (for its similarity to the flapping of the wings) or the "corona effect." Ohta showed some results from his experiments in wavelet-based image processing before concluding his talk. For further information, please contact:

Mutsumi Ohta
NEC C&C System Research Laboratories
Terminal System Kenkyubu
1-1, Miyazaki 4-chome, Miyamae-ku
Kawasaki, Kanagawa 213, Japan

Shigeru Muraki's (Denshi Gijutsu Sogo Kenkyujo) talk on "Processing of Three-Dimensional Volumetric Data" consisted primarily of his own work. His first slide showed his work on resurrecting a three-dimensional "blobby" clay-like model from a two-dimensional slide. This type of computation-intensive, three-dimensional imaging work led Muraki to be interested in wavelet techniques. He then gave a brief explanation of the three-dimensional equations for wavelet expansions along with the data storage scheme to be used. In a second example, reconstructions of Dr. Spock's three-dimensional facial features were shown for six different resolution levels where 512, 1,024, 2,048, 4,096, 8,192, and 16,384 functions were used. A final example showed how the technique could be applied to sets of two-dimensional magnetic resonance imaging (MRI) slices, with ray tracing to give a near-realistic three-dimensional image. The presentation concluded with results from experiments where 2,048, 8,192, and 32,768 functions were used and a vertical planar cut was made through the head to reveal the interior of the skull for each resolution level. For further information, please contact

Shigeru Muraki
Denshi Gijutsu Sogo Kenkyujo
1-1-4 Ume-sono
Tsukuba-shi 305, Japan

--Mei Kobayashi, IBM Japan

* * * * *

INSTITUTE FOR NEW GENERATION COMPUTER TECHNOLOGY'S (ICOT) KL1 "ENGINE"

My most recent report on ICOT ["Japan's Fifth Generation Computer Project," *Scientific Information Bulletin* 16(3), 31-35 (1991)] described many of the project's goals and expectations. Please refer to that for more details.

ICOT is trying to develop hardware, called PIM (parallel inference machine), which will run programs written in their language, called KL1 (Knowledge Language). The targeted final system is called the Fifth Generation prototype system and is expected to be about 1,000 processors along with their associated system software. This system is intended to demonstrate the usefulness of logic programming and its potential uses in artificial intelligence, databases, business tools, etc. The developers also specifically list numeric and scientific applications, although these seem far down among the areas that they are working on.

The KL1 language was developed as an extension of another logic programming language, GHC (Guarded Horn Clause). It is a kernel language, i.e., application programs as well as system software can be developed. Thus, it has goal reduction and goal scheduling, memory management, interrupt handling, input/output (I/O) processing, compiling, etc. Also, it has various parallel execution control functions such as pragma, distributed load control, priority control, and meta-control. In fact, the functions required are so complex that ICOT scientists have decided to use an intermediate language (KL1-B). Thus, users write in KL1, which is compiled into KL1-B for an abstract machine. A runtime system is designed for virtual hardware, which models a tag architecture and multiprocessor shared memory. This approach eases portability and program readability; only the low-level hardware dependent part needs to be altered for any real machine.

The fundamental driving features for the implementation of KL1 into a real parallel computer are that as many processors as possible should be kept busy, few processors should be wasted, and compatibility with software should be kept. ICOT's Keiji Hirata, in a recent paper ["Research and development of KL1 engine," *ICOT Journal* 32, 2-13 (1991)], comments: "What kind of hardware architecture can support such an efficient parallel execution? We can find no proper answer to this question presently." Nevertheless, ICOT's researchers have generally agreed that the MIMD (multiple instruction, multiple data) model is most appropriate. Consequently, ICOT is

developing five different MIMD machines with differing architectures in order to compare and evaluate implementation issues. All share one feature: that about 10 central processing units (CPUs) are connected by a single bus into a "cluster" within which main memory is shared. Clusters are interconnected by a network that differs from one PIM to another. The idea of a hierarchy is simply to reduce the problems associated with trying to connect many CPUs with low latency and high throughput.

Five different industrial manufacturers are developing the different PIMs. Differences between them include machine instruction sets, number of CPUs per cluster, coherent cache methods, and network topology as mentioned above. These are called PIM/p, /c, /m, /i, and PIM/K and were described in more detail in my report cited above. An earlier machine, Multi-PSI, was developed in the middle of the project. In addition to the PIM machines, there are several associated projects only loosely connected with ICOT. One set is being performed at Keio University under the direction of Profs. Anzai and Amano, under the name (SM)^2, Sparse Matrix Solving Machine. (Alas, the name notwithstanding, (SM)^2 does not appear to be appropriate for numerical sparse matrix computation.) A single cluster of 20 MC 68000 processors began operation in 1986. More recently, the ATTEMPT (A Typical Testing Environment for MultiProcessor sysTems) is trying to find applications that run efficiently on thousands of processors and quantitatively evaluate their behavior. ATTEMPT-1 is a commercialized version based on a Futurebus that tries to emulate various types of cache protocols. The Keio professors specifically want to study the kind of logic simulation needed in designing digital circuits for cell arrangement, wiring problems, and logical synthesis.

By no fault of ICOT's, the large collection of different machines produced at different sites is confusing for observers who are not actively keeping track of the research.

Please note that ICOT will host the International Conference on Fifth Generation Computer Systems (FGCS), 1-5 June 1992, in Tokyo. For information, contact

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--David K. Kahaner, ONRASIA

* * * * *

REAL WORLD COMPUTING PROGRAM

The Real World Computing (RWC) Program [alias, New Information Processing Technology (NIPT)] is to be a 10-year program by the Japanese Government [Ministry of International Trade and Industry (MITI)] to lay the technological foundations for the information society that Japan sees as occurring in the 21st century. Information systems of that period are viewed as being based on several key technologies (as opposed to a single one), including massively parallel computing, optical computing, neural computing, and logic programming. The RWC program aims to establish theoretical foundations for these technologies, explore applications, and study how they can be integrated. Flexible integration is seen as an important goal in order for information systems to be able to deal with real world problems. Program organizers view the evolution of computing systems as moving from conventional computing (where numbers, documents, and data are processed) through Fifth Generation (logic-based) computing (where knowledge is processed) to flexible information processing (where intuitive information can be processed), which is the heart of the RWC program. Examples of applications of RWC systems include incompletely specified (ill-defined) problems such as understanding of situations in a noisy environment, large-scaled problems such as simulation of social and economical phenomena, and real-time problems such as man-machine interface with virtual reality and autonomous control of intelligent robots.

The main technological aspects of RWC are seen as follows:

(1) Development of the computational bases. This includes research separately on general-purpose massively parallel systems and special-purpose neural systems, optical computing and optical devices, and system integration.

(2) Theoretical foundations and the development of "novel" functions. The former includes all aspects of representation, storage and recall of information, information integration and evaluation, and learning and self-organization. The latter includes research into flexible recognition and understanding of multimodal information, flexible inference and problem solving on flexible information bases, flexible/autonomous control, and flexible interactive environment for man-machine interface.

The program will be organized around five fundamental policies:

(1) A central laboratory (probably at or near the Electrotechnical Laboratory (ETL) in Tsukuba) at which common research will be performed, students and postdoctoral candidates trained, etc., and several distributed laboratories (which may not all be in Japan) for more highly individual research.

(2) A competitive principle. During the first half of the program, a large number of different approaches will be supported, and during the second half research themes will be evaluated and concentrated. The program deliberately has a clear description but only vague, multiple subtargets.

(3) Interdisciplinary and international cooperation. Active joint research with ETL, universities, etc. and subcontract research from Japanese and foreign research organizations. MITI feels that this program represents a real change of direction for its support of science: from one that invested in near-market development to one that was fundamentally research oriented.

(4) Publication of research achievements to promote true international cooperation and open reporting via conferences and symposia. As much as possible documentation of RWC results will be in English. However, it is expected that many informal and internal documents will be in Japanese.

(5) Establishment of infrastructure for research by setting up a high-speed network. A significant network linking more than 10 locations in Japan and a few overseas is planned to give researchers access to central laboratory facilities, such as a massively parallel computer, shared information database, etc., as well as to provide an electronic notice board, electronic mail, and electronic meeting capabilities.

The RWC program schedule is as follows. The Master Plan was completed by the end of March 1992. Also during March a RWC mission went to Europe to explain the program and to discuss participation in the program either as members of the research partnership or as subcontractors. By the end of April the Feasibility Study Committee will authorize the Master Plan. Sometime during this summer (June/July 1992) the RWC Partnership will be established. The partnership will actually begin activities in October 1992, with a call for participation, subcontractors, etc., and with an application deadline near the end of 1992. Thus, substantial money will not enter the program until late in 1992; the 1992 fiscal year budget is only about ¥900M.

For general information contact

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--David K. Kahaner, ONRASIA

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THE THIRD INTERNATIONAL CONFERENCE ON SCIENCE AND TECHNOLOGY POLICY RESEARCH

Introduction

The Third International Conference on Science and Technology Policy Research was held in Oiso, Kanagawa Prefecture, on 8-11 March 1992. The previous conference, the second in the series, was held at the same venue in January 1991. These conferences were organized by the National Institute of Science and Technology Policy (NISTEP) of the Science and Technology Agency (STA). In recognition of the fact that science and technology (S&T) transcends national boundaries, the conference reviewed science and technology policy from a global point of view. It considered the questions "how can science and technology best be advanced for the promotion of the global economy?" and "how can the policy contribute to the challenge?" The meeting last year focussed on the issues of what should and what can be done in S&T policy research. It seemed to this observer that the papers this year were better integrated with each other.

General

The proportion of participants from overseas at this conference was relatively large--they numbered 33 of the 140 attendees. A great many of the participants knew each other, which made the discussions and interactions much more animated than is usually the case at such meetings. Thirty-two papers were presented during 2 days; they were divided into six sessions:

- Science and technology policy research
- Public policy
- Innovation process
- Internationalization
- Research and development strategy
- Recent developments on science and technology situations: general trends and environment

The conference closed with a roundtable discussion at which Prof. Ikujiro Nonaka of NISTEP presented a summary of the highlights of the meeting.

Discussion

In the *science and technology policy research* section the papers mainly dealt with models and paradigms. Drs. Kinji Gonda and Fumihiko Kakizaki of NISTEP proposed an "[illegible]" model to relate science, technology, and industrial competitiveness. Drs. Fujio Niwa, Hirovuki Tomizawa, and Fumito Hirahara of NISTEP conducted indicator analysis of Japanese science and technology. They argued that Japanese basic research and scientific infrastructure are poor in comparison with other developed nations. A method for technological and new products forecasting called Delphi Technological Forecasting was presented by Dr. Akitoshi Seike also of NISTEP. Science and technology indicators were also topics of a paper by Dr. Giorgio Sirilli of the Institute for Studies on Scientific Research and Documentation of the National Research Council of Italy. His main indicators were research and development (R&D), innovation statistics, patents, technological balance of payments, trade in high tech products, and bibliometrics.

The effectiveness of policy measures was reviewed in the session on *public policy*. Prof. Marie Anchordoguy of the University of Washington, who is currently conducting research at Hitotsubashi University, presented a summary of a study she conducted for the Office of Technology Assessment on Japanese industrial policy and their supercomputer trade and targeting policies. She argues that "government-sponsored cartels" and cooperative R&D projects and subsidies give the Japanese supercomputer makers an advantage in international competition. While that may be correct, her treatment of Cray Research as a company comparable with Hitachi, Fujitsu, or NEC gives a very wrong impression of the competitive edge held by the Japanese. These three Japanese companies are huge, broad-based companies, whereas Cray is a single product business with much less capital. Dr. Kinji Gonda of NISTEP studied the effect of industrial location policies on regional R&D in Japan. He reported that regional R&D activities are shifting from applied to basic research. Dr. Xiang-Hao He of the Research Center of Management Science, China Association of Science and Technology, who spent last year as an STA fellow at NISTEP, analyzed how Japan gained international competitive advantage. He concluded that Japanese export is vital to their economic growth, that their industrial system is divided into those that are export oriented and those that are domestic market oriented, and that Japanese industry considers R&D efforts as a main driving force for gaining competitive advantage. The system for the education and professional development of engineers was studied by Prof. F. Karl Willenbrock of the Department of Engineering and Public Policy, Carnegie Mellon University. In the ideal system, he said, there would be a strong emphasis on science and mathematics in pre-college, a multi-route system in college so that options can remain open longer for the student, and multiple entry points permitting people to reenter to upgrade their skills.

In the session on *innovation process* Prof. Wesley Cohen of Carnegie Mellon University considered the tradeoff between the size of a firm and its diversity in promoting technological progress. He concluded that having a large number of small firms will result in a greater diversity in innovations but that an industry with larger firms will show a more rapid rate of technical advances on the approaches to innovation. Dr. Hariolf Grupp of the Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany, reviewed the dynamics of science-based innovation in North America, Japan, and Western Europe. In his analysis he primarily used patent data. Dr. Diane Hicks of the Science Policy Research Unit, University of Sussex (she spent a year as a research fellow at NISTEP), examined the extent to which scientific research of Japanese corporations is globalized on the basis of the number of published papers. She concludes that Japanese companies actually rely heavily on Japanese sources. An attempt to identify the techno-economic paradigms through analysis of the innovation process was reported by Prof. Masaaki Hirooka of the Faculty of Economics, Kobe University. One of his conclusions based on the analysis of the technological lag of Japanese industries was that Japan reached the level of Western nations in the early 1970s. Profs. Don E. Kash, Institute of Public Policy, George Mason University, and Robert W. Rycroft, Center for International Science and Technology Policy, George Washington University, discussed "simple technologies," which can be understood by individuals and whose value results from revolutionary innovations and "complex technologies," which are difficult for individuals to understand and whose value results from incremental innovations. For the former, they said, public policy must focus on generating new ideas that lead to innovations, whereas for the latter the public policy needs are greater and more complex. Prof. Fumio Kodama of NISTEP, who is currently a visiting professor at the Kennedy School of Government, Harvard University, reported on the effectiveness of technology transfer in large and small firms.

The session on *internationalization* was led off by Justin L. Bloom of Technology International, Inc. Mr. Bloom had served as the Counselor for Scientific and Technological Affairs at the American Embassy in Tokyo for 5 years in the late 1970s. He reported on American corporate investment in Japanese research facilities and among the points he made were (1) direct investment is much greater than imagined, (2) U.S. firms have not encountered much Japanese Government resistance in making technological entries into Japan, and (3) Japan tends to buy R&D while the U.S. sets up facilities from scratch. Orlando Camargo, Research Associate, NISTEP, reported on foreign firms conducting R&D in Japan. His study was based on the results of a questionnaire survey of senior R&D managers and senior representatives of these companies; 52% of the 132 firms surveyed responded. The biggest problems these managers faced were the hiring and retention of personnel. China's policy on international cooperation of science and technology was discussed by Liu Yong-Xiang, Counselor of Science and Technology, Embassy of the People's Republic of China. He strongly emphasized that the policy of China was to actively promote international cooperation with all countries with which it has friendly relations. Prof. Jon Sigurdson, Research Policy Institute, University of Lund, Sweden, reported on the impact of the internationalization of corporate R&D on science and technology policy.

Five papers were presented in the session on *R&D strategy*. Prof. Richard Gordon, Silicon Valley Research Group, University of California at Santa Cruz, based on a study of the U.S. semiconductor industry, reviewed linear and evolutionary models for innovation and global competition and suggested a third, "social organizational" model. Dr. Yutaka Kuwahara of Hitachi, Ltd., discussed global R&D management and suggested "inclusive-interactiveness" and "visibility" as new concepts. He defined the former as "internal existence of the subject which performs judgment of value and does activities based on intentions" and the latter as "clearness in concepts, procedures, and practices." Drs. Yasunori Baba and Ikujiro Nonaka of NISTEP discussed the creation and transference of manufacturing knowledge in the die and mold industry; this industry was selected because, while it is a shadow industry, it is absolutely indispensable for manufacturing and thus a good indicator of trends. They state that the Japanese model of knowledge management can systematically integrate "two opposing types of knowledge into a powerful source of knowledge creation/advancement." Prof. Kei Takeuchi of the Research Center for Advanced Science and Technology, University of Tokyo, discussed "technological conglomerates." These conglomerates are characterized by an existence of a core technology and a continuity in personnel and management.

The final set of papers was presented in the session on *recent developments on science and technology*, which was divided into general trends and environmental issues. Of particular interest to me were the papers by Prof. Jon D. Miller of Northern Illinois University, who discussed the scientific literacy and public attitudes towards international competition in scientific research and manufacturing of Americans, and by Dr. Hajime Nagahama of NISTEP, who presented the characteristics of public understanding of science and technology in Japan. Using the definition of scientific literacy as having a minimal understanding of the processes of science, a minimal understanding of scientific terms and concepts, and a minimal understanding of the impact of science on society, Miller reported that scientific literacy in the United States is 6.9%. Among Nagahama's findings were (1) the fraction of young males interested in "topics and news on science and technology" is falling, (2) the understanding (i.e., "awareness") of scientific knowledge such as "DNA" or "lasers" reflected school education content, and (3) attitudes of the Japanese, Americans, and West Europeans towards science and scientists varied considerably.

Conclusion

As we all know, the relationship between the United States and Japan, which former Ambassador Mike Mansfield often described as the most important in the world, has sailed into turbulent waters. Recent statements by Japanese political leaders and the very acrimonious rhetoric by American leaders have added fuel to the fire. There are a number of underlying causes to this friction. Among them are the hardships suffered by the Americans because of the recession, the trade imbalance, perception among Americans that the Japanese do (or will) not play by our rules, cultural differences, and language difficulties. As I listened to the presentations, two other equally important factors were apparent. One is that observers often have preconceived ideas and look for and find evidence to support them. An observer can make correct observations but can report them in such a manner that a wrong view or impression is conveyed. This was clearly evident in one of the papers presented by an American participant. Another is that we Americans tend to blow hot and cold on issues. This year one of the major Japanese "bad guys" is the *keiretsu*,

which is a term for the Japanese industrial cartels or conglomerates; some of the famous ones are Mitsui, Mitsubishi, and Sumitomo. We feel that the manner in which the keiretsu operate, e.g., the group bank making capital available to a member company at low interest rates, gives that company an unfair advantage over its foreign competitors. Many American speakers used the term keiretsu often; last year that term was not used at all. A few speakers gave the impression that the keiretsu evolved relatively recently, that it was nurtured by the Japanese Government to help their industry. Actually, though, the system came into being in the 17th century and has existed in one form or another ever since. Prior to and during the Second World War, it was called zaibatsu. These two examples were disturbing because the American participants at this conference were scholars who are knowledgeable about Japan and, yet, one of them reported observations that conveyed a wrong impression and several jumped on the keiretsu bandwagon. The Japanese are tough and often difficult competitors. In order for us to compete successfully with them, it is imperative that we learn about their ways and plan our actions accordingly. This requires that we study their ways objectively with an open mind.--*Sachio Yamamoto, ONRASIA*

* * * * *

VARIOUS COMPUTING ACTIVITIES IN TAIWAN

The International Symposium on Algorithms '91 and visits to Academia Sinica and the National Center for High Performance Computing in Taiwan are summarized.

by David K. Kahaner

SUMMARY AND BACKGROUND

I first visited Taiwan, Republic of China (ROC), in December of 1990 [see my report "Computing in Taiwan," *Scientific Information Bulletin* 16(2), 23-29 (1991)]. The current report provides updates and further perspective. At the time of my first visit I commented on the lack of applications research. I still sense something of a disconnect between what appears to be very high quality academic research and industrial needs. However, in the area of computing, the soon-to-be-opened National Center for High Performance Computing will go a long way towards bringing research and development (R&D) closer together.

Please refer to the earlier report for general background on Taiwan. Suffice to say that Taiwan's 20+ millions are enjoying a remarkable period of economic growth. The country's foreign exchange reserves including gold exceed $90B (greater than Japan's) and are projected to go beyond $100B in 1992, driven in large part by a trade surplus of about $13B in 1991. Per capita income, $8,800 (third highest in Asia behind Japan and Hong Kong), is growing about 9% annually, as is general economic growth in spite of the world-wide recession. The savings rate has been hovering slightly over 30%. Since 1971 the country's gross national product has gone from $6.6B to $180B. Europe is a huge trading partner, too: $14B in 1991, with a trade surplus of over $4B. In addition to trade with the West, there is a growing volume of trade with mainland China, up nearly 50% last year (1991). So-called cross-Strait trade was more than $4B for the first 10 months of 1991. Recently there have also been calls for a loose economic community between Taiwan, Hong Kong, and the coastal provinces of southern mainland China, perhaps even including Singapore.

A government-backed consortium led by the Taiwan Aerospace Corporation (TAC) has proposed to purchase 40% of McDonnell Douglas' commercial jetliner operations for about $2B, and the deal will go through in January if the U.S. and ROC Governments agree. Purchase of such a large and important industry would have a significant impact on Taiwan's industrial base and would certainly require heavy supercomputing usage. In a related matter, a recent announcement in a Taipei paper asked for a bid on supersonic wind tunnel measurement systems. The country already has at least one supercomputer and several dozens of U.S. mini-supers.

Since 1990 Taiwanese companies have invested more than $400M in the Bay area of northern California. Billions more have been invested in Southeast Asia; in 1990 Taiwan became Malaysia's number one investor, $2.3B in that year. More than $500M has been invested in Vietnam since it was opened to outside investors several years ago. In addition, there has been major Taiwan investment in Mexico, anticipating the open border to the United States.

INTERNATIONAL SYMPOSIUM ON ALGORITHMS '91 (ISA'91)

Almost 140 scientists met at the Academia Sinica, in Taipei, Taiwan, 16-18 December 1991 for the Second International Symposium on Algorithms. ISA'91 was organized by the Institute of Information Science, Academia Sinica, and National Tsing Hua University, with cooperation from the Special Interest Group on Algorithms (SIGAL) of the Japan Information Processing Society. The first symposium was held last year (1990) in Japan as SIGAL International Symposium on Algorithms. The participant distribution was approximately as follows.

Country	No.
Taiwan	79
U.S.	19
Japan	17
Hong Kong	6
Germany	6
Sweden	4
Canada	3
China	1
Singapore	1
India	1
Australia	1

Included in these numbers are several Taiwan-born scientists, now working in the United States.

I was pleasantly surprised to discover that the conference organizers had not only issued a Proceedings but had arranged for Springer-Verlag to publish this as part of their *Lecture Notes in Computer Science*. Very careful advance planning permitted all but the invited papers to be included in this book. For those, readers can contact the individual authors.

ISA'91 Algorithms
Springer Lecture Notes in
Computer Science #557
W.L. Hsu, R.C.T. Lee (editors) 1991

Because of the wide distribution of this book, I will only make a few general comments about the papers at this symposium.

The goal of the ISA is to promote a forum for Pacific Rim researchers as well as those in other parts of the world to exchange ideas on computing theory. The last two words here are important in the context of this symposium. While "algorithms" has a wide variety of meanings, ISA participants are concerned almost exclusively with discrete algorithms. The papers focused on sorting, permuting, the discrete aspects of computational geometry, combinatorial optimization, graph traversal, etc. Such algorithms have applications in virtually any problem area in which counting, enumerating, or selecting is significant. A typical one is to design the wiring path in VLSI to minimize space, crossovers, etc. Although a few papers dealt with parallel or distributed algorithms, these were in the minority.

Although potential applications abound, ISA papers actually emphasized theoretical aspects. Coming from a mathematics background, I felt right at home with the tone of the papers, although the techniques used were quite different from those I was familiar with. Most papers presented elegant theorems analyzing discrete algorithms, data structures, or generalized graphs and expressed results as "order" or other limiting relations. Here is a typical definition: "We call such an algorithm 'competitive' if its cost performance is at most a constant multiple of the ideal cost." There was very little evidence of actually using a computer, except perhaps to experiment as a way of suggesting direction, or verify an analysis. Although the subject is different, this is analogous to the style in some theoretical numerical analysis papers. That kind of analysis can ultimately be important, although research has been much more practically oriented.

To succeed in such research it is only necessary to have capable scientists--equipment and other expensive facilities are secondary. Of course, this is one reason that ill-equipped research institutes sometimes concentrate in these areas (not the case for the host institution). Thus it is not surprising that there is an almost seamless flow of research results moving around the world in this field. There appeared to be a great deal of cross fertilization, including students of Western scientists graduating and establishing positions in other countries. It did seem that many of the key directions were set by Western papers. But the level of sophistication in almost all the papers was very high, and I spotted excellent work from just about every country that contributed. There really wasn't a "ringer" in the bunch.

From the Asian side, my own favorite papers were as follows.

- Inagaki (Nagoya, Japan) et al. on constructing shortest watchman routes in a polygon. The watchman route problem deals with finding the shortest route from a point back to itself, so that every point in the polygon can be seen from at least one point along the route.

- Ho (Academia Sinica, Taiwan) on three-dimensional channel routing (for VLSI), which tries to minimize the number of "vias," connections between different levels of the configuration.

- Chan (Hong Kong) et al. on path algorithms for robots minimizing total distance traversed. This was one of a series of very excellent papers on geometry.

- Ibaraki (Kyoto, Japan) et al. on a problem with application to the testing of logic circuits by applying a (limited) selected set of test inputs. Of course, one wants to make correct decisions with minimum testing.

- Chan (Hong Kong) et al. on how to make use of a hypercube computer that has some faulty nodes to run an algorithm requiring a full binary tree. I was impressed last year with related work from these authors (see my earlier report).

For additional details about ISA'91 contact

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ACADEMIA SINICA

The ISA'91 symposium, described above, was held in the Academic Activity Center of the Taiwan Academia Sinica (Academy of Science). Academia Sinica was founded in 1928 on the mainland and then moved to Taiwan in 1949. The Academia has two basic missions: conducting scientific research and coordinating scientific activities of other government research institutes and universities. The 19 institutes at the Academia are shown in Table 1.

The older institutes were established first on the Chinese mainland, although only 2, Mathematics and History and Philology, were moved to Taiwan intact; for 11 others personnel and equipment were left behind. Several years before an institute is officially established, a preparatory office is first set up (denoted by "pre" in Table 1). At the beginning these offices are mostly planning, but eventually become full fledged research facilities. Note that not all institutes count administrative staff in the figures given in Table 1, so numbers are rough approximations and may not be comparable between institutes. I was told that the total staffing is well over 1,000, although it fluctuates because of part-time employment.

I was fortunate to be able to have a lengthy conversation with

Dr. Ta-you Wu
President, Academia Sinica
Taipei, Taiwan, ROC

Dr. Wu, 84, was trained as a physicist with a Ph.D. from Michigan and published his first book, *Vibrational Spectra and Structure of Polyatomic Molecules*, in 1938. After World War II he headed the Theoretical Physics Section of Canada's National Research Council and later was Chairman of the Physics Department at the State University of New York at Buffalo. He has had a pivotal rule in the development of science in Taiwan since the mid-1950s and has been President of the Academia since 1983. He was mostly responsible for the science development program that sent thousands of Taiwanese abroad to study and eventually to return and staff the country's universities and research institutes. Another of his proposals was to limit all academic administrative appointments to a once-renewable 3-year term. A recent public opinion poll showed that he was one of the two most popular men in the country. In 1984 he won the Magsaysay Award, roughly the Asian equivalent of the Nobel Prize. In May 1991 he and U.S. President Bush received honorary Ph.D. degrees from Michigan, and Wu has a wonderful photo on his wall commemorating this event.

Dr. Wu explained to me that in Taiwan responsibility for development of science and technology is divided in three: the Ministry of Defense has its own budget and research agenda and is responsible for technologies related to military needs; the Ministry of Economic Affairs for various research institutes and science and technology related to industrial development; and the National Science Council (NSC) for all academic programs relating to basic, applied, and social science. Academia Sinica is somewhat special, as it belongs directly to the Presidential House (Taiwan's White House). As Academia president, Wu reports directly to Taiwan's President; thus his voice is loudly heard. The current Academia budget is on the order of $30M annually. President Wu spoke strongly about the distinction between basic (fundamental) research and other approaches; it is clear that he favors and has strongly supported the former.

Table 1. The Various Institutes of Academia Sinica

Institute	Date Established	Staff
Physics	1928	72
Chemistry	1928	79
History & Philology	1928	103
Mathematics	1941	48
Botony	1962	155
Ethnology	1965	33
Modern History	1965	58
Economics	1970	55
Zoology	1970	36
American Culture	1974	46
Biological Chemistry	1977	44
Social Sciences & Philosophy	1981	69
Earth Science	1982	87
Information Science	1982	70
Computing Center	1984	NA
Statistical Science	1987	65
Biomedical Science	pre 1981	251
Atomic & Molecular Science	pre 1982	25
Molecular Biology	pre 1982	133
Chinese Literature & Philosophy	pre 1989	42

Nevertheless, all is not perfect. The original intention of the Academia Sinica was that it would serve as consultant to the President on academic related matters. However, I was told that in the past this function was rarely used, and they have become another (large) research institute. Staff can submit research proposals to NSC for funding support just like any university faculty, but they cannot admit students and do not perform any instructional function. Many Taiwan scientists feel that the resources being devoted to the Academia's research program should be re-oriented toward directly assisting the country's industrial infrastructure. In the area of computing, similar views have been expressed by Taiwan-born, U.S.-based scientists, who feel that much more emphasis needs to be placed on practical systems-building experiences and less on highly theoretical paper studies. My own opinion is that it would be healthy to better tie R&D done at the Academia to that supported by other ministries, as these seem more aligned with the country's needs.

The ISA symposium was sponsored by the Institute of Information Science (IIS). There were informal opportunities to visit its building, but no chance to see any other institutes. Computing facilities were comparable to well-equipped Western laboratories: an N-cube, two Iris graphics and about 50 other Unix workstations, and plenty of PCs. There is access to an ETA-10, which is run by the Computing Center. There is a computer vision laboratory with image scanners, camera, image processors to support two-dimensional animation and three-dimensional visualization work, stereo vision, and neural network research. There is a long-term project in natural language understanding for Mandarin Chinese. The N-cube gives some opportunity to perform parallel processing research. This is related to architecture design, compilers, and parallelizing various constructions within existing languages. There does not appear to be any significant research in numerical methods, either theory or implementation. There is interesting robotics research related to dexterous manipulation, coordinated motion of multiple robot arms, and simulation. As the ISA symposium would suggest, there are about a half dozen people working on the theoretical aspects of discrete (combinatoric) algorithm development. Finally, there are significant efforts in the areas of real-time operating systems, high-speed networking, software methodologies, and a small effort VLSI layout design.

A new eight-story building is being built to be finished before 1994, sufficient to house more than 50 Ph.D. researchers. The institute publishes an English language research journal, *Journal of Information Science and Engineering*, which contains articles from Taiwanese researchers (not primarily those at IIS). Electronic access has recently been expanded to Internet service, allowing file transfer, Telnet, etc. While Chinese is the daily working language, almost all IIS scientists can function adequately in English. Many have spent substantial time in the West, and a few speak excellent colloquial English. Information about this institute generally, or the journal in particular, can be obtained from the following.

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I was told that the Institute of Information Science is typical of those at Academia Sinica. It is essentially run by the research faculty with very few administrative duties. It is a research institution. There are no teaching duties because there are no students; instead, research is supported by many full-time assistants. Many faculty do, however, offer courses in nearby universities, and there are the usual seminars, conferences, etc. Many IIS staff were heavily occupied with the ISA symposium and there wasn't much other activity while I was there. I did not visit the Institute of Mathematics, but the printed materials that I was given discuss work in rank inequalities for chordal graphs, probability, algebra, and number theory. There does not appear to be any significant activity in numerical analysis. A quarterly *Bulletin of the Institute of Mathematics* has been published for almost 20 years, and since 1976 another quarterly, *Mathmedia*, for less esoteric articles.

With nearly 1,000 scientists in so many disciplines, Academia institutes are individually worth serious examination. The preceding comments are meant to provide background and overview material only.

NATIONAL CENTER FOR HIGH PERFORMANCE COMPUTING

In December 1990 I reported on the plans for a national supercomputer center in Taiwan. Almost 1 year later I decided to see how things were coming along. I met with

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Also at the same address is Dr. Kuo-Wei Wu, who was on leave from Cray Research to help with NCHC's planning. He has now resigned from Cray and is a Deputy Director of NCHC. (A year earlier Wu had explained some of Taiwan's goals in the area of supercomputing.) Chang, Wu, and a good-sized administrative staff are currently housed at National Taiwan University, in the city of Taipei. However, a 15,000 m^2 building is almost complete. This is in Hsinchu Science-Based Industrial Park (HSIP), 70 km south of Taipei, the and site of two major national universities, National Tsing Hua (with about 4,500 students and about 450 faculty) and National Chiao-Tung University. Hsinchu's model seems to be Tsukuba Science City in Japan; there are also somewhat similar places in Korea, Singapore, etc. It is usually referred to as Taiwan's "Silicon Valley I."

I did not visit the park this year but had been in Hsinchu a year earlier and wrote about it then. On a site of nearly 1,000 acres there are about 150 factories. An additional 500 acres have been obtained and plans are to house another 150 companies within 5 years. Presently, production values (%) of companies in the park are as follows.

Computers and peripherals	49.0
Integrated circuits	30.0
Telecommunications equipment	17.0
Opto-electronic equipment	1.7
Miscellaneous	2.3

HSIP, like other commercially based high-tech industrial parks with many tenants, has some ailing companies, some with products that are less high-tech than authorities might want (one company wanted to develop robots and is now engaged in making window-washing machines), and some whose high-tech 3 years ago is now just labor saving. There is talk both about tearing down the park's walls (and eliminating tenants' tax breaks) to integrate its companies better into the society and also setting up similar parks in other parts of the country such as Kaohsiung. Nevertheless, HSIP is a must-stop for anyone interested in industrial development in Taiwan.

Taiwan is certainly not the first country in Asia to build a nationally accessible supercomputer center, but it hopes to benefit from experiences in other places. Planning took place over 4 years and NCHC is organizationally placed under the National Science Council and will be a national laboratory there. It is expected that in late 1992, when the facility finally opens, it will serve both the academic as well as the industrial community. The emphasis is to be on application expertise. NCHC is operated in 5-year phases, the first ending in June 1995. This phase was budgeted with $89M, about half for computer-related hardware and software systems. NCHC's director is chosen by NSC from relevant university faculty. Under him are five divisions.

- Administration
- Operation
- Hardware/Software Management
- Research/Development
- Education/Promotion

The last two distinguish NCHC from a pure cycle-shop and make it more like one of the National Science Foundation (NSF) Centers in the United States. In addition, special interdisciplinary laboratories and projects will be established as needed. Current plans are for a scientific visualization laboratory, and projects in molecular modeling and public domain mathematical library development, and these are to be integrated within and across the divisions. Staff will be about 100, similar in scale to the NSF Centers.

NCHC is to be hooked up to a local network (FMAN) within Hsinchu's industrial park. In addition, it will be hooked to TANET (Taiwan Academic Network), a T1-based public network sponsored by the Ministry of Education and part of Internet. In addition, there will be long-haul T1- or T3-based dedicated lines set up to major universities and research institutes that need such access. NCHC will be internally networked with the Fiber Distribution Data Interface (FDDI).

Chang and Wu emphasized to me that one of NCHC's major functions is to provide expertise. They expect 1,200 potential users during 1992. This will have to be all in the last third of the year, as the hardware is not scheduled to come on line until late summer. By 1995 they are hoping to support at least 2,000 users. Major applications are expected to be molecular modeling, computational fluid dynamics, electron device simulation, structural analysis, atmospheric science, and earthquake wave studies. They are anticipating the usual bevy of academic exchanges, newsletters, seminars, etc., not only focused on how best to deal with existing applications on NCHC's equipment but also anticipating new computing environments such as highly parallel computers that will become user-practical in the future.

At this date a final selection of hardware has not yet been made. The expected vendors have all submitted proposals and these are now being evaluated. The specifications call for a high-performance computing engine, a front-end system, and a large number of workstations for visualizations, computing, and software development. The supercomputing engine will be installed in two stages, 1992 and 1994, to ensure that new equipment will be installed as it becomes available.

I am very optimistic about the future of this center. The planners have emphasized that they are NOT interested in building Taiwan's own supercomputer or engaging in advanced computer science software research, but instead want to concentrate on the research associated with applications. NCHC staff are already "on the road," providing training via courses and seminars on techniques related to high-performance computing. They are funding university faculty to port and tune their existing programs to make better use of whatever supercomputer is going to be installed. (Typically, existing programs will not take maximum advantage of vector or parallel architectures.) I am optimistic also because in recruiting staff for the new center, double talents are being emphasized, application fields first and then good knowledge about computer architecture, algorithms, etc. The hope is to get advanced computing to the end user quickly. User groups based on application area are being formed. Finally, the vendor that is finally selected will be required to provide not only systems support but application research support, researcher exchange, seminars, and so forth.

David K. Kahaner joined the staff of the Office of Naval Research Asian Office as a specialist in scientific computing in November 1989. He obtained his Ph.D. in applied mathematics from Stevens Institute of Technology in 1968. From 1978 until 1989 Dr. Kahaner was a group leader in the Center for Computing and Applied Mathematics at the National Institute of Standards and Technology, formerly the National Bureau of Standards. He was responsible for scientific software development on both large and small computers. From 1968 until 1979 he was in the Computing Division at Los Alamos National Laboratory. Dr. Kahaner is the author of two books and more than 50 research papers. He also edits a column on scientific applications of computers for the Society of Industrial and Applied Mathematics. His major research interests are in the development of algorithms and associated software. His programs for solution of differential equations, evaluation of integrals, random numbers, and others are used worldwide in many scientific computing laboratories. Dr. Kahaner's electronic mail address is: kahaner@xroads.cc.u-tokyo.ac.jp.

JAPAN ATOMIC ENERGY RESEARCH INSTITUTE (JAERI)

Computer-related research at the Japan Atomic Energy Research Institute (JAERI) is summarized.

by David K. Kahaner

INTRODUCTION AND SUMMARY

The Japan Atomic Energy Research Institute (JAERI) was established in 1956 to perform the research and development (R&D) associated with implementing the country's nuclear program. It is funded under the Science and Technology Agency (STA), which is an arm of the Prime Minister's Office.

Currently, the major projects are as follows.

- Nuclear energy production system including high temperature gas-cooled reactor and fusion reactor
- Nuclear safety
- Radiation applications
- Nuclear ship

JAERI has an administrative headquarters and a radioisotope school in Tokyo. The main research center and a fusion research center are in Tokai and Naka, small towns on Japan's Pacific coast about 70 miles north of Tokyo. Radiation chemistry research occurs both near Osaka and at Takasaki, halfway between Tokai and the Japan Sea side of the main (Honshu) island. Nuclear ship research occurs at the northern tip of Honshu. (Japan's nuclear waste disposal facility is also near the northern end of Honshu, but this is not run by JAERI.)

JAERI's budget and staffing grew rapidly through the mid-1980s but have essentially been constant since 1985, nearly $880M (about 90% from STA) and about 2,500 staff (one-third each research, technician, and administrative). JAERI is currently building a high temperature test reactor, operating fusion experimental equipment, building a synchrotron orbital radiation (SOR) facility, etc.; plant and equipment are expensive and account for the very large budget.

Japan generates approximately 30% of its electrical power by nuclear means, although this figure would reduce to 17% if other electrical generating plants were used to capacity. Sentiment in the country is modestly antinuclear, but the major reason that JAERI budgets have not increased is that nuclear technology is now mature. The nuclear ship, MUTSU, has been behind schedule and immersed in controversy for years; it is now scheduled to be decommissioned in the spring of 1992.

I spent 1 day at Tokai visiting with scientists in the Computing and Information Systems Center (CISC), which is essentially the computer support organization. They also perform some of their own research. CISC is run by

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I also had an opportunity to meet with three members of his research staff,

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and also with

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Interestingly, Dr. Iizumi and I had some common background, as he has visited the reactor facility at the National Institute of Standards and Technology (NIST) in Maryland several times.

During the time of my visit, Prof. Eugene Wachspress (University of Tennessee) was also visiting JAERI in order to give a series of lectures on

various topics in the area of numerical linear algebra related to reactor problems. As is well known, the nuclear industry provided some of the earliest problems in numerical analysis and was a significant motivator for the development of large-scale supercomputers. There are still major problems associated with all aspects of nuclear energy that require extensive computer analysis. While new civilian power plants are not being built, there are many applications of nuclear energy. Also there are many research reactors and medical applications. Finally, there are the knotty questions about disposal, leakage, etc.

In his lectures, Wachspress focused on sparse matrix methods for linear equations and also for eigenvalue problems. These techniques are often at the heart of nuclear application codes. Another purpose of his visit was to assist JAERI in thinking about how best to use new computers. He remarked to me that there is a great deal of time and money spent getting old programs operational on new machines. This includes fitting old algorithms into parallel and vector architectures when new algorithms especially designed for these computers would be much more efficient. This is a common problem at any laboratory that has a significant development effort in place using large, existing program packages.

CISC has two Fujitsu VP2600 supercomputers, used mostly for running large nuclear codes. One is at Tokai, the other at nearby Naka where the fusion research is located. There are also three other Fujitsu M780 series mainframes and many workstations. In Tokai the computers are served by a 157.5-GB disk, 88-GB optical disk, tapes, etc., and there is similar equipment at Naka. There is a 6-km on-site local area network (LAN) (205 Mbps) and a 9.2-km optical fiber connecting Tokai and the fusion laboratory. The Tokai laboratory has been connected to Bitnet (56 Kbps) for several years and is currently connecting itself to Internet. There are also two DECnet links, one serving the fusion research community (I commented in an earlier report that worldwide this group is heavily DEC and VAX oriented), another that supports TCP/IP. (Interestingly, JAERI's earliest computer was an IBM 650, the same model that I began computing on at the Watson Laboratory, then at Columbia University.)

CISC has a total staff of about 55, 10 involved in R&D (including 2 senior scientists) and 20 in systems, networks, etc. The remaining 25 are contractors, mostly for operations. Some interesting statistics for last fiscal year follow.

No. of users	1,855
CPU time used (h)	26,965
No. of time sharing sessions	526,619
No. of batch jobs	659,265

CPU Utilization (%):

Nuclear fusion research	45.3
Fundamental research	19.7
Nuclear safety research	17.9
Other	17.1

Dr. Akimoto explained to me that most of the applications software work is still being done in Fortran, although new projects within CISC are using C and Lisp. As expected, younger scientists prefer the newer languages.

Research at CISC is centered around the following.

Robots at work inside nuclear power plants. (Parts of this environment must be among the most hostile imaginable.) Working in Lisp, CISC scientists have been simulating how human-acts could be realized by a human-shaped intelligent robot (HASP: Human Acts Simulation Program). This is part of a 10-year program begun in 1987 to develop basic and underlying design technologies for intelligent robots; to develop the basic technologies for very advanced, intelligent nuclear power plants; and peripherally to create and transfer artificial intelligence (AI) techniques in the nuclear field. Akimoto pointed out that a paper on HASP has been submitted to "Expert Systems and Computer Simulation in Energy Engineering," 17-21 March 1992 at Erlangen, Germany.

Computer integration of nuclear design programs. Building a nuclear reactor is a complex process involving engineering from diverse areas. Currently, JAERI scientists are constantly running large programs, taking the resulting output of one and using parts of it for yet another calculation. One CISC project is to integrate the programs (which are frequently produced by different commercial vendors) and use expert systems to ease the transition between different programs.

Vectorizing. Much of the work at CISC centers around getting the best performance from existing computers on standard workhorse programs (hence Wachspress' remark above). Since the mid-1970s more than 50 nuclear programs have been vectorized. To assist them in assessing what might be expected from the Fujitsu VP machines, CISC has assembled a suite of benchmark programs for testing vectorization. The list below includes programs of direct interest to JAERI and also some standard benchmark problems that readers will recognize.

SLWALF	Simulation Code for Alpha-Particle Heating
AEOLUS	Three-Dimensional (3D) Magnetohydrodynamic Code
STREAM	Thermal Hydraulics Analysis Code
VDIRECT	High Temperature Test Reactor Code
SRAC	Thermal Reactor Standard Neutronics Code System
CITATION	3D Neutron Diffusion Code
TWOTRAN	Two-Dimensional (2D) Neutron Transport Code

DOT35	2D Discrete Ordinates Neutron Transport Code
FPGS	Composition, Radioactivity, Decay Heat Calculation Code
PHENIX	2D Diffusion Burnup Refueling Code
BERMUDA	Neutron-Gamma-Ray Transport Code System
ISOFLOW	Melting Process Analysis Code
DSMC	Gas Kinetics Code by Direct Simulation by Monte Carlo Method
SPIN	Spin-Spin Interaction in 2D Ising Model
VIENUS	Visco Elastic Stress Analysis Code
SONATINA	Seismic Response Analysis for High Temperature Gas Reactor (HTGR) 2D Vertical Core
RELAP5	Light Water Reactor (LWR) Transient Analysis Code
WIND	3D Wind Field Calculation Code
JPEC	JAERI Performance Evaluation Code for Basic Operations
LLLC	Lawrence Livermore National Laboratory (LLNL) Loop Performance Analysis Code

Using these programs, JAERI computed the fraction of computation that was vectorizable and the speedups running on the VP2600 compared to their older VP100, both in vector and scalar mode (see Table 1).

On 40 programs of specific importance to JAERI, they gave me the following statistics.

Vectorization Ratio (%)	No. of Programs
50-60	2
60-70	5
70-80	8
80-90	2
>90	23

And the following vectorization speedups on the VP2600.

Table 1. Vectorization Ratios and Speedups for VP2600 and VP100 Computers

Program	Vectorization Ratio (%)	Speedup Vector/ Scalar VP2600	Speedup VP2600/VP100	
			Scalar Mode	Vector Mode
SLWALF	99	25	3.2	5.0
AEOLUS	92	6	3.1	3.4
STREAM	98	8	3.1	4.8
VDIRECT	97	6	3.2	2.9
SRAC	96	10	3.0	5.1
CITATION	94	10	3.1	4.7
TVVOTRAN	95	7	3.0	4.0
DOT35	87	4	3.2	5.3
FPGS	99	14	3.1	6.3
PHENIX	86	4	3.0	4.6
BERMUDA	90	6	3.0	3.4
ISOFLOW	99+	16	3.1	5.0
DSMC	90	6	3.7	6.1
SPIN	90	8	3.2	3.9
VIENUS	92	6	3.8	3.3
SONATINA	87	5	3.2	4.0
RELAP5	90	5	3.2	4.6
WIND	96	15	3.3	5.0
JPEC	99	14	4.0	7.0
LLLC	82	4	3.7	4.4

Speedup	No. of Programs
1-2	8
2-3	9
3-4	8
4-5	2
5-6	1
6-7	2
7-8	2
8-9	2
9-10	1
10-11	0
11-12	1
12-13	1
13-14	0
14-15	1
15-16	1
>16	1

Thus most programs result in only modest speedups. This is fairly typical for programs that were originally written for older scalar machines.

Two CISC scientists I met (Yokokawa and Kaburaki) have experience with parallel machines as well as traditional supercomputers. Dr. Yokokawa is a Ph.D. graduate of Tsukuba University and worked under Professor Y. Oyanagi (now at the University of Tokyo) and Professor M. Mori (University of Tokyo), two well-known Japanese numerical analysts. Dr. Kaburaki was coauthor of a paper on the use of Fujitsu's AP1000 parallel processor for Monte Carlo simulation of gas dynamics. This paper was presented at the recent joint Fujitsu-Australian National University workshop. Yokokawa and Kaburaki gave me another paper coauthored by JAERI and Fujitsu scientists on parallelizing the Monte Carlo program MCACE for the AP1000. This had also been presented at the aforementioned workshop. At the moment, Kaburaki is also working with N. Ito, another recent graduate from the University of Tokyo's

physics department on the development of a special purpose parallel computer (m-TIS) for doing Ising spin computations. Ito's primary thesis work was on using a supercomputer for similar calculations. He was not at JAERI during my visit, so I will report on this work later.

I also had an opportunity to learn about JAERI's scientific subroutine library, JSSL, from Mr. Harada. This was of special interest to me as I have done research in development of similar packages. I was mildly disappointed as this library is not really a current product; its last revision was in 1982. There is only a very small staff to manage and work on the library, and it is a big job to do so. JSSL does contain some excellent programs, such as MA21A originally from the Harwell library, but also some very old routines, including Crout reduction of matrices and Romberg quadrature. It did not appear to have any of the modern, standard programs such as those from Linpack, Eispack, Quadpack, etc. In fact, some JAERI scientists were surprised to hear that in the West, large quantities of high quality mathematical software are in the public domain and can be obtained easily and rapidly by electronic mail. Of course, some scientists are using this approach for their own personal research, but it is far from common, and in any case the routines have not made their way into JSSL. These observations were consistent with comments made to me by Wachspress, who noticed that among the Japanese scientists he met, awareness of developments in the West was uneven. Essentially all open research from any country is known here--and at a high level of absorption--but its distribution appears to be less uniform than in the United States or European Community. Electronic communication will go a long way, in my opinion, to assist scientists in accessing modern information from anywhere in the world. This is a very important trend.

ADVANCED TELECOMMUNICATION RESEARCH INSTITUTE (ATR)

The Advanced Telecommunication Research Institute (ATR) is described.

by David K. Kahaner

INTRODUCTION AND BACKGROUND

I first visited the Advanced Telecommunication Research Institute (ATR) more than 18 months ago, shortly after its 16K node Connection Machine CM-2 had been installed [see my report "The Advanced Telecommunication Research Institute (ATR)," *Scientific Information Bulletin* 15(4), 4-5 (1990)].

My current visit was hosted by

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who also provided a great deal of assistance in the editing of this report and whose patience is sincerely appreciated.

The ATR organization is complicated. It was established in October 1985 as a result of the privatization of the Japanese telephone company. At that time the Japan Key Technology Center (JKTC) was set up, funded mostly by the dividends from NTT stock that is owned by the Japanese Government. The Government now owns 60% of the stock of NTT. JKTC funds about 40 projects, of which by far the largest is ATR. JKTC top management includes representatives of various ministries [Ministry of International Trade and Industry (MITI), Ministry of Finance (MOF), and Ministry of Posts and Telecommunications (MPT)], although ATR is viewed as the major laboratory associated with MPT (the Electrotechnical Laboratory (ETL) is associated with MITI even more directly). Actually JKTC provides only 70% of the funding for the four laboratories (or projects) that represent the science component of ATR. The laboratories were established as 7- to 10-year projects; two will expire in 1993 and two in 1996, although there is every reason to think that they will be renewed, perhaps with slightly different emphasis. NTT and 140 other Japanese companies have also provided private investment and the four laboratories get the remaining 30% of their funding from this. The same companies also fund ATR International, which supports the laboratories and provides research facilities and support structure. ATR International has a president and board of directors. It is jointly owned by NTT and the 140 other Japanese companies with NTT holding about 60% of its stock. To make it more complicated, the three key people at ATR International are retired from MPT, the regional Kansai government in which ATR is located, and NTT. Each of the individual laboratories has a president: two are from NTT, one from KDD, and one from MPT. In addition, many of the staff members within each laboratory are part of a particular NTT organization. Thus there is a great deal of vertical information flow, and for similar reasons the laboratories are rather independent. Practically, though, ATR can be considered as part of the NTT family.

The four ATR laboratories are colocated in a building in Kansai Science City, a new area about halfway between Kyoto and Osaka. I was told that building costs were about $70M. Inside the ATR building there is a fifth laboratory [called NTT Communication Science Laboratories (CSL)], which started operation in July 1991. This operation is not part of ATR but is just leasing the building space. Right behind ATR, NTT owns land, where they may establish a new building for this laboratory. If this happens, it will be the only official NTT laboratory outside of the Kanto area. Almost all the researchers now at CSL were transferred from NTT laboratories in Musashino or Yokosuka in the Tokyo area.

When I first visited in 1990, ATR was the only building in sight. Now it is surrounded by others in various stages of construction, including several hundred residential townhouses. Across the street a large Sumitomo is going up. Across from that, a big project called the Keihanna Convention Center is under construction. (KEI-HAN-NA is a combination of the abbreviation of three words, Kyoto, Osaka, and Nara.) It will be a convention center with hotel and so on. Those readers who have been to Japan should imagine what Tsukuba Science City (near Tokyo) must have looked like during its earliest days to get a sense of the area around ATR. Like Tsukuba in those days, many

ATR staff members feel isolated from more established parts of Japan, but this will change as the community develops roots.

Almost half the ATR management are on rotational assignment from a couple of NTT's laboratories or divisions. And the other half are mostly from laboratories of KDD (international telephone company), NHK (seminational radio and TV corporation), and CRL (Communication Research Laboratory of MPT). Most of the staff members are also rotational, coming for a few years. About one-fourth are from NTT, but other Japanese companies are also represented. There are also visiting Western researchers. I met four, three Americans and a Frenchman. Their appointments were temporary, 1 year at a time, but apparently could be extended several times by mutual agreement. Each of the four laboratories has a few senior scientists who are either *permanent* or at least on very long term assignment. These people provide the technical leadership and continuity.

Rotation of staff in and out of the laboratories provides a collection of new ideas but also leads to some underutilization of equipment that is ordered for use in one near term research project but is of less interest to the next. However, even in such cases there is residual benefit, as the overall research projects are generally well planned and are all heading toward some very long term goals, with natural near term revisions and adjustments. I was told that most equipment will be used in succeeding projects. However, staff turnover is definitely ATR's major organizational concern, and I was told that there are new plans to develop more permanent positions. This is a difficult issue, because the ATR laboratories are not permanent. If ATR hires any permanent employee they have to provide for the employee's long-term career plan. I was told that one approach is to hire only those that can easily be absorbed back into a sponsoring company, a university, or a research institute when the ATR projects end.

Staff experience is also an issue. As is typical of Japanese companies, there are relatively few employees with Ph.D. degrees. Companies that support ATR clearly use the laboratories as a place to put younger employees for training. There was some difference of opinion among the Japanese I spoke to as to whether an assignment at ATR was in anticipation of good work to follow (back at the home company), a reward, or a banishment. This is very company dependent. However, most companies send their good engineers because they are representatives of the company and they want them to look good.

Researchers who come with definite ideas about what to work on seem to fare quite well. I was told that each and every researcher knows what he will do at ATR because there are negotiations on this subject before he joins. However, there is the usual trial and error associated with research topics. Perhaps Western researchers have even more flexibility in this matter. I believe, though, that many of the younger Japanese are assigned to projects. Most new staff will work on a project suggested by an advisor or department head, by joining an existing project, or by doing research alone. There is also the problem of what some of these Japanese will do when their ATR assignment is complete. Of course, most will return to their companies, but several have gone on to universities. One expressed concern to me that the basic research he was doing at ATR might not be supported in his home laboratory and hoped that he would be able to find a good spot when he returned. On the other hand, some returning employees from Sony, Matsushita, and others have been known to get overseas assignments (e.g. to the United States, Germany, the United Kingdom, etc.) after their ATR assignments. So coming to ATR is a kind of stepping stone for them. And, in general, many researchers have been able to make excellent use of the experience, results, and ideas, etc., from ATR and, in some cases, were placed in very good positions. This is especially true for NTT. On balance, a few years at ATR seems to be a good thing for the scientists involved.

The four laboratories are mostly independent, although they are housed in the same building. The independence is enhanced by giving each laboratory its own president as mentioned earlier. This was a bit strange to me, as the total staffing of 260 is low enough that there could be a great deal of interaction, although each of the laboratories is aiming at its own specific research goals. However, given the complicated funding arrangements, it is not too surprising.

A good example of the independence is the use of the Connection Machine. This was purchased primarily for the computational studies of cognitive processes carried out in the Auditory and Visual Perception Research Laboratory. While it is extensively used, I was told that some time is available (there might be some differences of opinion about this), but researchers from other laboratories and even other groups within this laboratory are occasionally discouraged from using it. Dr. Nakane explained to me that funding for the machine is for specific research jobs (rather than for other purposes or mere interest). This requires careful accounting and designation of users. Still, such an important resource ought to be of great help to scientists throughout ATR.

Laboratory staffing is as follows. In 1990, total staff was 262 and total budget was ¥7.[illegible]B, about $50M. This does not include the space occupancy fee that ATR International charges to each of the research and development (R&D) organizations. I mentioned this figure to a colleague who had spent 3 years at

ATR, and he felt that the budget figure was severely underestimated, perhaps because of the complicated funding situation. He thought that a more realistic figure was twice that.

Name of Laboratory:

Communications Systems	37
Interpreting Telephony	52
Auditory & Visual Perception	57
Optical & Radio Communications	40

Research Staff Breakdown:

Invited international researchers	24
Invited domestic researchers	15
Other researchers	144
Permanent staff researchers	9

Other Staff:

Assistants	42
Clerks	28
ATR International	6

Publications and patents have been growing since ATR's founding.

Papers:

Year	International	Domestic
1986	5	45
1987	21	282
1988	80	414
1989	140	422
1990	169	448

Patents:

Year	No.
1986	15
1987	70
1988	120
1989	160
1990	223

The figures above were given to me by Dr. Eiji Yodogawa, president of the Auditory and Visual Perception Laboratory (AVPL) (E-mail: yodogawa@atr-hr.atr.co.jp). ATR publishes the *ATR Journal*, which is mostly in Japanese. However, they also publish annually a bound collection of the staff's technical reports. Many of these are in English, and all have English titles and abstracts.

The four laboratories and their primary activities are as follows.

Communications Systems:

Main goal: Human-oriented intelligent communication system

- Communications with realistic sensations, automatic three-dimensional (3D) shape acquisition, recognition, comprehension, modeling, manipulation, and display.
- Nonverbal interfaces, recognition of facial and eye-gaze directions, understanding gestures and hand movements, integration of visual and speech information.
- 3D image databases.
- Cooperative work environment for design of solid objects.
- Automatic generation of communication software, extraction of real intentions, use of visual language to give specifications accurately, human deliberative mechanisms in software design, knowledge base, easy to use specification description language.
- Security, cryptographic techniques for large capacity (image) communications, secure telecommunication networks.

Optical and Radio Communications:

- Optical intersatellite communications, optical beam control, optical modulation/demodulation.
- Advanced antennas, active array technology for mobile antennas, methods of mitigating multipath propagation problems, microwave circuit integration, signal processing.
- Optical and electronic devices, growth and characterization of semiconductors with precisely controlled atomic configurations, nonlinear optical devices.

Interpreting Telephony:

Main goal: Automatic interpreting telephone

- Speech recognition and synthesis, speech database.
- Interface between speech and language, spoken language processing, knowledge base, speech and language integration.
- Machine translation, grammar for analysis of Japanese, dialog interpretation, contextual processing.
- Advanced dialogue processing, contextual processing.

AUDITORY AND VISUAL PERCEPTION LABORATORY

My visit was confined to the Auditory and Visual Perception Laboratory, which has three departments. Its main goal is an improved human-machine interface.

Visual Perception Department:

- Visual perception mechanisms: motion perception, binocular stereopsis, character and word perception, image concept formation
- Brain activity measurement (eye movement, etc.)

- Pattern recognition: neural network models for handwritten characters, spatiotemporal patterns

- 3D object recognition

Cognitive Processes Department:

- Cognitive processes for visual information: neural computing models of pattern vision and spatial vision

- Parallel processing mechanism: mathematical analysis and synthesis of neural net models, information processing using neural net models

- Learning and motor control mechanisms: neural net models of human motor control, integrated learning of somato sensory and visual information

Hearing and Speech Perception Department:

- Hearing mechanism: auditory peripheral models, auditory preprocessor for speech recognition

- Speech perception mechanism: coarticulation model and application to speech recognition, speech recognition using neural nets, speech prosody

In this laboratory one of the most active researchers is

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Kawato's background is in biophysical engineering and he was previously a faculty member at Osaka University. Kawato is one of the few semipermanent members of the research staff and he is collaborating with almost a dozen younger researchers on an astonishing variety of projects. This research has generated nearly 50 papers since 1987, most in Western journals or in Proceedings of international conferences. Kawato gave me a long list of the projects that he is currently working on (outlined below), but I had an opportunity to discuss only a few of these with his coworkers.

Learning trajectory control:

- Learning control experiment of rubbertuator Softarm by feedback-error learning neural net. Inverse statics and inverse dynamics. Six-muscle arm model. Sensor fusion for object manipulation.

- Feedback error learning for closed loop system. Models of regions of cerebellum. Recognition of manipulated objects by motor learning.

Trajectory formation for arm and articulator:

- Explanation of Fitts law by neural net. Learning acquisition of forward dynamics of speech articulator on CM-2 using an electromyogram (EMG) as control input.

- Combination of cross validation method and new information criterion to estimate generalization capability of neural net models. Pattern generation and recognition using neural net.

- Minimum-muscle-tension-change and minimum-motor-command models based on biomechanical data of monkey musculoskeletal system with 17 muscles.

- Human arm movement using Optotrack and recording EMG.

- Measurement of EMG, articulatory movement and acoustics for speech articulator and neural net model.

Computational model of visual cortices and sensor fusion:

- Use of CM-2 to implement Markov random field (MRF) model of images and learning of potential energies for hidden variables without teachers.

- Hierarchical MRF based on conditional probability and application to pattern recognition.

- Shape from shading based on forward and inverse models of optics.

- Integration of visual, somatosensory, and motor control information for object manipulation.

There is a great deal of neural net research in progress, including new algorithms and applications to physical situations of speech and vision. The traveling salesman problem is another application being studied. The CM-2 is used heavily now for simulations. (M. Hirayama showed me several very interesting demonstrations.) During my first visit, the ATR staff members were still learning about this machine and usage was low. I was told, however, that the machine is now much busier. It is extensively used as a neural network simulator for the previously mentioned studies of human perception, motor control, and some other related topics. Some of the computations/simulations on CM-2 require an enormous amount of machine use, say, 10 days of continuous time, for example. Presently the CM-2 is working in "exclusive mode" but not in "TSS mode." This is partly because of some problems with the TSS operating system (OS) and partly because of some decrease of computational performance in TSS mode,

which seem to decrease the efficiency of the CM-2 usage. However, the newest version of TSS OS seems to have resolved these problems and is to be installed very soon. However, it has been used heavily enough so that requests are being heard that it be replaced with a more powerful one. The current machine was purchased on a 3-year installment plan and included 32-bit floating point units. ATR is hoping to get one with 64-bit floating point units in the future, but at the current time this has not happened. (I believe that there are three Connection Machines in Japan--one at ATR, a second at the Institute for Computational Fluid Dynamics in Tokyo, and a third at an undisclosed location, probably a private company.)

One of the most interesting aspects of ATR's research is how tightly coupled it is to biological models of real sophistication. A significant aspect of the work seems to be associated with modeling and then verifying models with complicated physical measurements. One example of this is related to understanding the mechanism behind the articulatory to acoustic transform, i.e., to understand the process by which linguistic intentions become speech. Speech production entails extraordinary coordination among diverse neurophysiological and anatomical structures. These unfold through time to produce a complex acoustic signal that conveys to listeners something of the speaker's intentions. ATR's research has used measured movements of the articulator (upper and lower lips and horizontal and vertical jaws) and EMG data from four separate muscle groups and used these to train a neural net to generate motor commands to the articulators.

Another especially elegant example is work by Kawato on studying the trajectory followed by human arms. Kawato proposed that this minimizes the time integral of the square rate of change of the torque. Based on this model he has developed a neural network that reproduced Fitts law (sometimes called speed-accuracy trade-off of arm movement) and also used it to study feedback-error-learning for ill-posed problems. Human sensory-motor control, such as arm movement, involves a number of ill-posed problems.

I think that it is unusual to find so much biophysical expertise being put to use in modeling, especially coupled with advanced computer hardware and software. In the area of vision, there are projects to automatically generate 3D images from a series of stereo-pairs and another fascinating project to analyze, quantify, and predict our response to optical illusions. Projects like these require careful eye-movement measurements and distance monitoring, as well as a deep understanding of current ideas in cognition. These are difficult mathematical problems, too. Our brain essentially solves the inverse problem of reconstructing a 3D visible surface from the data of a two-dimensional (2D) image projected onto the retina. (Solutions of this problem are related to extensions of regularization techniques, some of which are very well known in computational mathematics.) There certainly is plenty of hardware available for experimenting. While I was there two technicians from Canada were visiting ATR to help set up a pair of Optotracks, sophisticated distance measuring equipment costing in the neighborhood of $60K each. Workstations are everywhere, along with associated peripherals. The ATR building and laboratories are large, spacious, and very well equipped. One of the only places in the United States that I know of, where comparably subtle work is going on, is at the Massachusetts Institute of Technology's (MIT) brain research department, and there is a substantial flow of visitors between ATR and MIT. (Immediately after my visit, T. Poggio from MIT arrived to give several days of lectures.)

CONCLUDING REMARKS

My visits to ATR have been cordial and revealing. About 10 scientists I met were enthusiastically willing to describe their research, although the independent laboratory structure made it difficult for me to get a full picture. My visits have been highly organized and tightly time constrained. The laboratory I visited is doing very excellent basic research, but I still haven't seen the work on interpreting telephony or communications systems in other laboratories, and I would like to go back and learn about these. What I have seen is a group of capable Japanese, supplemented by a substantial number of long-term Western visitors. There are still some birth pains both at ATR and in the surrounding area; ATR is barely 5 years old. Finally, procedures need to be established to insure that ATR is not only a training ground for young Japanese scientists and a temporary or sabbatical station for Western ones but also to insure that ATR will develop the continuity and world-class stature that will enable it to accomplish the major long-term goals it has set for itself.

NEUROCOMPUTING AT MITSUBISHI ELECTRIC

This article profiles Mitsubishi Electric and describes the work in its Neurocomputing and Optoelectronics Group in Osaka.

by David K. Kahaner

INTRODUCTION

Western scientists, especially those in universities, often have only vague ideas about the real size of some Japanese high tech companies. A good example is Mitsubishi. While probably best known in the West for its automobiles and shipbuilding activities, I wonder how many realize that Mitsubishi Electric (MELCO), which does not include either of the automotive or ship construction companies, is itself a $27B company at today's exchange rate, with just under 100,000 employees, and celebrated its 70th anniversary in 1991? See my report, "Flexible Automation," *Scientific Information Bulletin* 16(1), 27-35 (1991), for a description of some of Mitsubishi's shipbuilding activities. For a more general overview see "Mitsubishi Electric Corporation: Its Basic Research Focus," *Scientific Information Bulletin* 16(4), 39-42 (1991). Note that in January 1992 the Yamato I, a 280-ton prototype superconducting propulsion system ship, was launched by Mitsubishi Heavy Industries (separate company from MELCO), and that MELCO and other parts of the Mitsubishi family will participate on a bid for the 409-km/100-minute Seoul-Pusan, Korea, bullet train project (total cost is estimated near $10B), to be completed before the end of the century.

MELCO products fall into four areas.

- Consumer products (audio-visual, home electronics, and appliances)
- Information, telecommunication, electronic devices, and systems
- Industrial and automotive equipment
- Heavy machinery (locomotives, nuclear power equipment, etc.)

with the first two nearly equal and accounting for about 60% of sales. Research and development (R&D) expenses are as follows in billions of yen, approximate dollars (¥125/$1), and percent of sales.

Year	¥B	$B	% of Sales
1987	94.6	1.28	4.8
1988	101.9	1.16	4.9
1989	118.5	0.95	4.4
1990	145.1	0.82	4.3
1991	159.8	0.76	4.9

The main R&D activities continue to be electronics, new energy sources, new materials, and biotechnology. MELCO has quite a number of research laboratories. The oldest, the Central Research Laboratory (CRL), near Osaka, has been in existence under this name since 1944.

- Central Research Laboratory (Osaka)--Basic R&D of future products and of fundamental technologies for existing and new product lines.
- Manufacturing Development Laboratory (Osaka)--Development of technologies for all of MELCO, including in-company manufacturing equipment and systems, processing, and insulation.
- Materials and Electronic Devices Laboratory (Osaka)--Development of metals, ceramics, high-density materials, and electronic devices and analysis of existing technologies.
- Industrial Electronics and Systems Laboratory (Osaka)--Development of factory automation, public utility, and automotive systems and equipment.
- Consumer Electronics Laboratory (Kyoto)--Development of new electronic product lines and mass production technologies for these products.
- Consumer Products Laboratory (Kamakura)--Development of personal information-communications equipment, functions for home electrical appliances, systemization technologies, new-function electronic products, and product-evaluation technologies.
- Industrial Design Center (Kamakura)--Industrial design activities related to all MELCO products.

- Computer and Information Systems Laboratory (Kamakura)--R&D of computer- and information-related systems and equipment.

- Communication Systems Laboratory (Kamakura)--Overall R&D of communication systems technologies and devices.

- Electro-Optics and Microwave Systems Laboratory (Kamakura)--Development of new technologies for components in fields such as electro-optics and microwave systems.

- LSI Laboratory (Osaka)--R&D of design and production technologies for integrated circuits (ICs), large scale integration (LSI), very large scale integration (VLSI), and discrete semiconductors as well as the creation of new products.

- Optoelectronic and Microwave Devices Laboratory (Osaka)--R&D of design and production technologies for optoelectronic and microwave devices and the creation of new products.

- ASIC Design Engineering Center (Osaka)--Development of custom LSI design technologies and support for the design of LSIs for use in in-company systems.

- MELCO Research Laboratory U.S.A. (Boston)

MELCO is currently constructing a synchrotron-radiation facility. It has an active superconductivity program and is working on 64-Mbit DRAMs, a GaAs semiconductor laser and field effect transistor (FET), an optical neurochip, a process using ultrafine ice particles as a cleaning agent in electronic device manufacture, semiconductor ceramic fiber (30-50 microns), and a very high integration digital signal processor. MELCO is heavily into advanced transportation, such as superconducting trains (mag-lev) and superconducting ship propulsion systems, and it supplies vast numbers of locomotives and related rail-stock to countries from China to Mexico.

MELCO is active in the Institute for New Generation Computer Technology (ICOT) program with the development of several versions of PSI, a parallel sequential inference machine, including the first one ready in Japan. One application is for a Japanese-English translation system. There are a number of other parallel processing projects including a high speed database machine and a parallel-syntax processor for man-machine speech recognition system. The company has produced more than 150,000 elevators and escalators, including a group that uses artificial intelligence (AI), expert systems, and fuzzy theory, and it has recently produced the world's first spiral escalator (installed in San Francisco). Similarly, it has a fuzzy controller for electric discharge machines, an expert system for insulation diagnosis, and a developing knowledge media station.

MELCO has the largest value added network in Japan (packet-switching) and is planning to use this to link 20,000 terminals in its corporate E-mail net, both Unix workstations in technical divisions and PCs in administrative divisions. A server will be installed in a local area network (LAN) used by each laboratory and a main server will be installed in the company's main office. When completed this year, it will connect 63 offices and 45 sales companies, hopefully reducing paperwork into the main office from its current 3 tons each day.

The company is also developing a number of products that will depend on using the ISDN (Integrated Services Digital Network) now being installed in Japan. For example, one home automation system monitors a home for gas leaks, fire, unlocked doors, and similar hazards. It can be initiated by a phone call.

My visit to MELCO was organized by

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I had met Banzhaf in the fall of 1991 when he presented a proposal at the New Information Processing Technology (NIPT) Workshop in Yokohama [see "First New Information Processing Technology Workshop '91," *Scientific Information Bulletin* 17(1), 51-60 (1992)]. Dr. Banzhaf is a visiting researcher on leave from the Institute for Theoretical Physics and Synergetics (Stuttgart) and has been at Mitsubishi's laboratory since September 1989. He is working in the neurocomputing group, run by

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Recently, Kyuma has received the Sakurai-Prize, the most renown in Japan for optical sciences, partially for his work on the optical neural chip (below).

Coincidentally, another German, Eberhard Lange (tel: +81-6-497-7050, E-mail: el@adm.crl.melco.co.jp), is also visiting this group. As is typical of visiting Westerners in Japanese companies, these appointments are temporary but can often be continued indefinitely by mutual agreement. Kyuma's group has

a total of 18 staff. Of these, five have Ph.D. degrees and three more have some prospect of obtaining this degree in the future. Typically, Japanese companies hire recent graduates with the equivalent of a bachelor's or master's degree. In the case of Kyuma's group, staff members have backgrounds in physics, applied physics, mathematics, materials, etc. There is very little recruitment of university trained Ph.D. holders. On the other hand, scientists working at an industrial laboratory have the opportunity to obtain a Ph.D. after a number of years and an appropriate amount of published research. In the United States it is also possible to obtain a Ph.D. while working, i.e., off campus, but these (U.S.) students are usually well known to their faculty advisor and there is a great deal of interaction between student and university. In Japan, the student-university connection is much weaker.

I've often wondered how it is possible for Japanese companies to produce so much interesting science with this kind of a system. One part of the reason is that good companies are extremely selective and only hire a few students each year--hopefully the very best. These then stay with their group for a long time, gaining experience, attending meetings, etc. Promising staff are often sent outside the company for training or additional education (see below). The group and project leaders are more senior and these people usually have advanced degrees, although often obtained via industrial publications as mentioned above. (Sometimes industrial scientists leave their company for academic positions.) The good Japanese research laboratories are also sprinkled with Western visitors. To be perfectly honest, the equation still does not compute for me, but the results speak for themselves.

Our original plan was to learn about MELCO's work in both neural nets and software development. However, the latter did not work out and my visit was restricted to optical computing and neural nets.

The most exciting project here has been the development of a fully optical neural chip, with eight neurons and (optically) adjustable weights. Dr. Kyuma has been the key person on this project, although I was shown the device by Mr. Jun Ohta (tel: +81-6-497-7049, E-mail: ohta@qua.crl.melco.co.jp). (Ohta is a good example of how a company like MELCO increases staff skills. Next fall, Ohta will move to Boulder, Colorado, to join Professor Thomas Cathey's optoelectronics group as a postdoctoral student.) The Mitsubishi chip is the most advanced to my knowledge. It was developed using molecular beam epitaxy (MBE) crystal growth technology and GaAs optoelectronic device technology. The first prototype, about a 1-foot cube, was developed in 1988. The current chip is mounted on a board together with other LSI devices and is in use in a demonstration neural computer hooked to a small workstation. The chip consists of three stacked layers: a light emitting diode (LED) array, in interconnection matrix, and a photodiode (PD) array. Both LED and PD arrays are placed in a crossbar with a dynamic spatial light modulator sandwiched between them as the interconnection weight matrix. The original neural network used spatial light modulators. The new neurochip uses variable sensitivity of its photodiodes, controlled externally, to adjust the weights. This allows vector matrix multiplication to be done in parallel, and because the weight matrix can be adjusted, it also means that the chip can learn. This is quite distinct from other approaches in which the interconnection weights are fixed in hardware and use Hopfield models without learning ability. The current chip is an 8x8. Ohta claims that their construction approach allows for about 2,000 neurons/cm^2.

A major ingredient of the Mitsubishi approach has been the use of quantized learning models. By that we mean that neural connection weights are not permitted to take on continuous values but instead are restricted to a finite set, often just two or three values. A quantized learning rule for back propagation is as follows:

(1) Start with random weights (continuous).

(2) Quantize into several discrete levels.

(3) Set spatial light modulator to value of value of discrete (hardware) weights.

(4) Present training and supervised signals to network.

(5) Calculate error by conventional back propagation method.

(6) Correct continuous weight by adding error.

(7) Repeat (2)-(6) for all training signals until connections converge.

In this approach, the quantized weights are built on the optical hardware and the continuous weights are stored in memory, allowing continuous changes in the weights and parallel optical implementation at the same time. Mitsubishi staff have shown that learning can be successful even if synaptic weights are quantized into only two levels. They have not only many simulation results but also implementation experiments using binary operating semiconductor light modulators (SLMs) to recognize the 26 alphabetic characters (Ref 1 and 2).

Several of the group members commented that they appreciated the opportunity to spend time talking to me and also listening over my shoulder while their colleagues described their

own research work. In fact, they felt that such interactions were very uncommon. This was extremely surprising to me, as is typically Japanese, the group works in a large airy room with modest partitions between desks, and I expected that very free interchange would be the rule rather than the exception. I was told that there is plenty of joint work but very little free time for researchers who are not working directly together on a project to sit around and talk about their work informally. An internal seminar was started last year but hasn't succeeded too well. Work hours are for working. Lunch is normally at one's desk, and seminars are after 1700; there is a commons room, but it is apparently rarely used. I remarked that I didn't find it troublesome to have seminars late in the day and that to a large extent lack of time to talk to colleagues was self-imposed. While there was general agreement, the scientists also felt that seminar times were symbolic, and the atmosphere discouraged the kind of cross-group interaction that is typical at Western research laboratories or at universities.

The neural net group is mostly doing algorithm development and simulation of different learning models. Some of this is clearly motivated by the parallel work on the optical neural chip described above (Ref 3). The focus of this work has been to try and solve the performance degradation problem that is usually associated with weight quantization. (Performance here is expressed by the number of steps necessary for successful training.)

Another problem with some connection to optical computation was shown to me by Lange. He has been studying the issue of identifying the face value of a postage stamp from its image. The interesting wrinkle here is that the stamp image is not digitized. Rather, a small number (32) of sensors directly read intensity and frequency from parts of the stamp, and it is their values that are input to a neural net, whose ultimate output is the stamp's face value. The stamp recognition project has succeeded (at least partially) in optical implementation. The neural network (competitive) has been implemented. Only the sensor device has not (so far). There is an internal report on this project, which is going to be published as part of a book (Ref 4).

Other work has been directed toward studying time varying spatial patterns, and Banzhaf has developed a network capable of removing distortions of patterns in time (Ref 5).

There is also work on genetic, evolutionary, or molecular algorithms applied, for example, to the traveling salesman problem (TSP), where the shortest tour in a given distribution of cities is looked for which visits all cities once and returns to the starting point. This problem is "classical," but it is a prototype of many nonpolynomial (NP) complete (i.e., problems that cannot be solved in time, which is a polynomial in the number of cities).

The group has access to MELCO's Cray Y-MP, which is in the Materials and Electronic Devices Laboratory, but most of their simulation work is done on workstations, sometimes used as a cluster. Given the large amount of simulation and the sophistication of the models, I am surprised that they don't have access to a parallel machine, such as a CM-2. The Industrial Electronics and Systems Laboratory does have an NCube, but the neural net group does not make use of it.

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INTERNATIONAL SYMPOSIUM ON THREE-DIMENSIONAL IMAGE TECHNOLOGY AND ARTS

Three-dimensional imaging from computers and film is reviewed. The International Symposium on Three-Dimensional Image Technology and Arts, held from 5-7 February 1992 in Tokyo, plus industrial tours to NHK, Sony, and Matsushita are described.

by David K. Kahaner

INTRODUCTION

Human three-dimensional or stereo vision evolved millions of years ago as a critical survival mechanism. Euclid wrote about it in 280 A.D., and research to duplicate our sense of depth vision with artificially produced images has been going on since 1600 (in 1890 the first three-dimensional movies were shown at the Paris International Exposition). Thousands of papers have been written. This report describes current work based upon the International Symposium on Three-Dimensional Image Technology and Arts, held from 5-7 February 1992 (in Tokyo), plus industrial tours to NHK, Sony, and Matsushita.

DISCUSSION OF SYMPOSIUM

The symposium was directed by

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(IIS is at the third part of the Tokyo University campus structure of Hongo, Komaba, and Roppongi). Nearly 130 scientists participated, with 37 papers presented, 17 from outside of Japan. (The Proceedings are entirely in English.) There is an active three-dimensional (3D) research community in Japan. Last July (1991) the Institute of Television Engineers of Japan ran a small international workshop at which related research in Japan and the European Community (EC) was surveyed. Research activities related to this are also described in my recent *Scientific Information Bulletin* article on virtual reality ["Virtual reality," 16(4), 43-45 (1991)]. Two upcoming meetings also worth noting are the following:

1. Second International Conference on Artificial Reality and Tele-Existence, 1-3 July 1992, Tokyo

   c/o Japan Technology Transfer Association (JTTAS)
   Plaza Mikado Bldg, 6F
   2-14-5 Akasaka
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   Conference chair:
   Prof. S. Tachi
   University of Tokyo
   E-mail: tachi@tansei.cc.u-tokyo.ac.jp

2. Japan Display '92 (12th International Display Research Conference), 12-14 October, 1992, Hiroshima

   Conference chair:
   Prof. S. Kobayashi
   Tokyo University of Agriculture and Technology
   2-24-16 Naka-machi
   Koganei, Tokyo 184, Japan
   Tel: +81-423-81-4221 x515
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Participation in the symposium was as follows:

Country	No. from-- Industry	Univ/Govt
Japan	~65	~35
U.S.	4	2
France	0	3
Canada	2	1
Germany	1	1
U.K.	0	1
Norway	1	0
Russia	0	1

[For reasons that I didn't understand, the industrial participants from the United States were small or very small companies. The Japanese were well represented by Toshiba, Sony, NHK, Fujitsu, Hitachi, etc. Does this mean that large U.S. industry is not interested in three-dimensional imaging? Certainly not, as there are products from Bolt Bernack and Newman, Texas Instruments, Tektronix, and others on the market already. So where were they? Perhaps this symposium was not too well advertised outside of Japan. Also, there was a meeting of the Society of Photo-Optical Instrumentation Engineers (SPIE) at about the same time in San Jose, CA. SPIE is a large meeting for which 3D imaging, especially holography, is one part, and it probably kept U.S. participation lower than normal.]

This symposium was supported by various electronics, television, and robotics societies in Japan, as well as the Ministry of Posts and Telecommunications (MPT). At the opening ceremony, MPT representative Saito explained that 3D is considered the most important research project that his ministry is currently undertaking. A funded 5-year project will focus on developing 3D image transmission technology to permit transmission of these images over optical fiber. Applications are seen to be TV telephones and conference systems. MPT has allocated $1.3M in FY92 and plans to allocate at least that much in subsequent years. Some cooperation with overseas research groups is being considered. (See also the electronically distributed report on MITI's plans for an "Image" laboratory, image.lab, 20 Feb 1992.)

I would like to express my thanks to several attendees who patiently explained many aspects of this technology to me, especially M. Pusch (Heinrich-Hertz Institute, Germany, and University of Tokyo), W. Fetter (SIROCO), R. Kroiter and P. Panabaker (Imax), M. Starks (3D TV), H. Tilton (Visonics), L. Lipton (StereoGraphics), P. McLaurin (University of South Carolina), M. Holzbach (Asaca), and J. Hamasaki (University of Tokyo). Of course, any errors are entirely my own.

It is useful to make the distinction between 3D, biplano-stereoscopic, and multiplano-stereoscopic images. (This dichotomy is due to L. Lipton.) True 3D images not only give the sensation of depth but allow observers to "look around" to their sides and perhaps even their back. Biplano-stereo images are produced from (only) two original images. They also can give a very realistic sensation of depth but have no "look around" capability. An observer moving his/her head while viewing a stereo image causes the image to shift slightly, but no occluded visual information comes into view and the perspective remains the same. Multiplano images are composed of more than two original images and do have some look around capability. An imaging system in which the image aspect changes depending on the observer's viewpoint is called autostereoscopic. In describing systems, the distinction between 3D and stereo images is often ignored. Indeed, there are "3D" and even "4D" workstations on sale, but this almost always means three-dimensional images projected onto a two-dimensional (2D) display device. I will try to use the terms accurately but won't change terms that authors use in describing their work.

In viewing the real world, it is known that the sense of depth is the result of ten or more different factors. For example, overlapping or occlusion, where one object obscures part of another, is a depth clue that does not depend on having two eyes. Another monocular clue is the image of road edges that we expect to be parallel. Similar monocular clues are related to retinal image size, areal perspective, shading, shadows, texture, etc. An important binocular clue to distance from the observer is the difference in angle between the viewing axes of left and right eyes when both are focusing on a point (convergence). Adjustment of the focal length of the crystalline lens (accommodation) is another clue, although this is mostly monocular. Binocular parallax is the most important binocular clue, relating to the fact that each eye sees a slightly shifted view of the image. Individuals differ greatly in their ability to use these clues either because of physical impairments, training, or some processing difficulties. This is much like color vision: people who lack it entirely discover so at an early age; others whose abilities are below average may go through their entire lives accommodating in other ways.

Images can be viewed on electronic displays such as TVs, cathode ray tubes (CRTs), flat panels, etc. or in hard copy form such as a photograph, plot image, and so forth. Viewing images may or may not require the use of special glasses. Anaglyph images require red/green glasses and most people are familiar with these from a large number of motion pictures (in the 1950s and 1960s) that required them, but their use can be traced back to as early as 1858. Anaglyph techniques can be used for viewing either still images on paper or dynamic images such as films. However, the current trend for films, video tape, or computer screen images has been toward polarized glasses instead, or systems without glasses.

Current work seems to be primarily directed toward stereo vision, although the main technique for full 3D imaging is holography, i.e., the reconstruction of the object wavefront. The original principle involves illuminating the object with a laser and simultaneously recording the reflected (or diffused) light from the object and a reference beam from the laser, creating an interference fringe pattern. The recorded pattern can later be illuminated with the same laser to reproduce the image. Work in holographic techniques has recently focused

on using conventional light rather than a laser and the creation of holographic stereograms, in which multiple images of an object are recorded by ordinary cameras at different positions and a hologram of each image is recorded sequentially. Holograms can provide a very high resolution and geometrically accurate image that can be viewed without glasses and in principle is indistinguishable from the original object. But initial enthusiasm for holography has waned somewhat as practical problems reproducing color and providing dynamic displays have not yet been effectively solved. Also, many techniques for holographic imaging produce images smaller than observers would like to see. As one researcher commented, holograms provide too much information, i.e., it isn't really necessary to completely reconstruct the wavefront to have an effective image. However, some of the most exciting developments in this area are being carried out at the Massachusetts Institute of Technology (MIT) media laboratory under the direction of Prof. Stephen Benton. Benton's early claim to fame was the invention of the white light transmission (dubbed rainbow) hologram and, more recently, the practical demonstration of holographic video. The laboratory is also working on holograms that are in full color, large size, animated, and can be totally synthesized by computer. Perhaps most importantly, this work has re-energized the field and forced researchers to take a more serious look at ongoing related work. At this symposium papers discussed applications of holography to medicine, cameras for holographic imaging of moving objects, and holographic TV using liquid crystal displays (LCDs). All the speakers pointed to Benton's work as years ahead, although he did not attend the symposium. (The work is known from his publications as well as his recent visit to Japan.)

Nevertheless, we are still years away from practical holography in our homes such as holographic TV. For example, any practical holographic display device relying on Benton's approach will require time-bandwidth products far exceeding those available with single channel acousto-optic modulators and will require other techniques such as multichannel modulators, parallelism, etc.

There are some other 3D techniques. An interesting one (S. Yamada, Shibaura Institute of Technology) involves projecting a sequence of cross-sectional "slices" on a screen whose diameter is changing. If the moving speed of the screen and the scanning speed of the images are fast enough and synchronized properly, 3D images can be recognized by an afterimage effect of human eyes. Yamada's main application is to viewing of medical images.

The "Pulfrich" effect is another that can be used for stereo vision on a normal television with glasses. This uses the brightness dependent delay-time of the human eye-brain to create the impression of a pseudo-stereo picture. This was demonstrated in Germany a year ago to broadcast pseudo-stereo via normal television equipment. Observers saw (with the help of a dark glass filter on the right eye-glass lens) stereo pictures when the objects moved from the right to the left on the screen. According to different velocities of objects in different depth levels, a stereo-picture was seen. One advantage of this technique is that the observer can choose between watching with glasses (stereo) or without (2D). The major disadvantage is that everything must be in motion. (There were no papers presented at this symposium on the Pulfrich effect.)

A serious issue with either 3D or stereo vision is viewer comfort. This can range from little-or-none to physiological disturbances that can cause nausea in some observers. Anaglyph images are often too dark or the color is poor. The process is simple in principle but tricky in practice. For example, when viewing computer screens, the color filters need to be matched to the screen phosphors. Otherwise there is cross-talk and the observer becomes confused by the stereoscopic information.

If right then left eye images are displayed sequentially from a source, and a synchronized shutter system in front of the eyes allows the right eye image to only enter the right eye, etc., then stereo vision can be observed. The shutter can be mounted in glasses that are matched with a display in which two constituent pictures are presented in alternation instead of simultaneously. The glasses occlude one eye and then the other in synchronism with the image presentation. This is often called "field sequential." This method avoids the retinal rivalry caused by anaglyph viewing but can introduce other discomfort such as the increase of flicker (on 60-Hz displays), the introduction of time parallax between the two images, or the possibility of "ghosting" between the images due to phosphor persistence. On computer displays flicker can be solved by increasing from 60 to 120 frame refreshes per second, although this is accomplished by halving the number of pixels that are painted per frame, perhaps leading to lower resolution. (Also see the comment by Starks below concerning "apparent" resolution of 3D images.) Most glasses-based shutter systems use LCDs, which work with polarized light. Currently, glasses using LCDs can provide good switching speed and reasonable extinction of the alternating lenses. The electro-optical polarizing shutters now in use transmit about 30% of the unpolarized input light (rather than 50% for perfect polarizers), and this reduces the image brightness a little, but in practice this does not appear to be a major problem. Some eye-glass shutters are

connected by wires to the monitor (tethered); others are controlled by infrared and are wireless. Another system uses a polarizing shutter mounted on the display device and eye-glasses with fixed (circularly) polarized lenses. While this reduces the complexity of the eye-glass system, the large screen-covering shutter is expensive to produce and is fragile. Lipton (StereoGraphics) commented that his company produced such systems for Tektronix but had many difficulties and is now using shutter glasses. For images that are generated by film (as opposed to those generated by computer), it is extremely important that all aspects of the production process, including film registration, color balance during the developing, balanced illumination during projection, etc., be maintained.

Flat panel displays are frequently used as part of a stereo imaging system. Among these, liquid crystal displays are popular. The "standard" type LCD is a direct matrix display, which has a structure of light modulating material sandwiched by horizontal and vertical stripe electrodes. The horizontal electrodes are scanned one by one and signal voltages are applied to all the vertical electrodes according to the image on the selected horizontal electrode. Plasma display panels and electroluminescent displays have fast response but LCDs do not, although they have high resolution and good color reproducibility. Increasing the number of scan lines rapidly decreases the average brightness of LCDs. But great strides have been made in this technology, and at least one symposium participant, T. Uchida (Tohoku University), felt that they will be mass produced and suitable for portable PCs and workstations in the near future.

An active matrix display has a diode or thin film transistor (TFT) at each pixel. These displays can provide fast response time (less than 10 ms), good display quality, and contrast better than 100:1. The main problems are that they are expensive to produce, especially in large sizes, and difficult to manufacture because of low production yields. For future displays Uchida felt that a target specification that would be achieved in a few years was as follows:

Resolution:	50 μm in pixel pitch
Diagonal size:	10-40 in, with 100 in desirable
Viewing angle:	$\pm 45°$ vertical, $\pm 60°$ horizontal
Response time:	15 ms
Reflectivity or transmittance:	60-80%
Contrast ratio:	50:1
Grayscale:	50-100

He also noted that among the most promising ideas was the use of optically addressed, amorphous silicon plus ferroelectric liquid crystal, with 5-10 μm resolution, 70 μs response time, and 60:1 contrast ratio. The main problem here seems to be that the active area is only about 1.4 cm, currently.

As mentioned above, 3D vision is partly physical, and partly psychological, and hence it is difficult to accurately quantify and resolve problems associated with it. For example, M. Starks points out that "ordinary consumer NTSC TVs with well done VHS stereoscopic tapes look equal or superior to any HDTV I've seen ... due to the fact that stereo will usually have a greater information content than mono and the highly sophisticated image processing systems in the brain have been evolved to take advantage of this." Another psychological issue is related to perception of images. We are accustomed to seeing close-up pictures of people framed by the edge of our viewing screen, photograph, etc. R. Kroiter (Imax) wondered if we will be as ready to accept heads cut off at the neck floating in space? (This may be a real concern, but not to everyone. McLaurin commented to me that "we have all adjusted to new presentation formats since their inception in cave dwellings and will continue to adapt. [Kroiter's] work is limited mostly to entertainment and not the distribution or presentation of information. When one leaves the realm of entertainment and enters scientific applications, one finds that it is information that is most important, not the general public's acceptance of an image for entertainment.")

Nevertheless, in the past few years many objective studies of binocular vision and perception have been performed and there is now a substantial collection of data that are being used in the planning of real systems. For example, work to determine the angular field over which 3D vision was effective has led to the design of large screen theaters by the Canadian company Imax. Also, the Russian author S. Amelianova wrote a paper on a very careful experiment to develop methods to evaluate observer's 3D vision thresholds in 3D perception and parallax. Amelianova's thesis was a 1991 Oscar winner for technical achievements. (Starks notes that Russian/Soviet work in 3D is substantial.) Other studies are even more focused on perception. For example, a strange but common visual sensation, named "Ganzfeld," concerns what happens when our total field of view is obscured by a single light color, such as in a fog or a white-out. This has been a basic topic for psychologists since the 1930s, and an experiment was reported at the symposium by M. Hara (Asahi University). The problem is far from settled, and much more research is needed to understand how we process binocular images.

I was surprised to discover the quality of work going on at the Industrial Products Research Institute of the Ministry of International Trade and Industry (MITI), located in the city of Tsukuba and presented by T. Takeda. This project is designed to measure basic ocular functions, eye movement, accommodation, and pupil diameter

during actual vision of 3D displays. The fundamental motivation here is to determine if there are any hazards to users, such as the concerns once voiced that the electromagnetic radiation from video display terminals (VDTs) would be harmful. The group has developed a 3D optometer that is capable of measuring these quantities yet allowing the eye to move freely with a 40° horizontal and 30° vertical range. One important result of their experiments is that the greater the depth stimulation presented by the stereo pictures, the more the observer's focus point shifts. Observers then perceive blurred images and struggle to reduce the blur and adjust to the depth perception. The adjustment process produces more visual fatigue than when viewing 2D images. Creators of stereo images strive to evoke as much depth sensation as possible to heighten their viewer appeal and may unwittingly add to viewer fatigue.

There is no doubt that entertainment has been a prime mover in this subject. Imax, mentioned above, builds large stereo motion picture systems that are used in theaters around the world. NHK, the Japanese governmental TV system, is hoping to develop stereo TV, and presumably its main customers will be ordinary viewers, not scientists. NHK scientists are already talking about broadcasting of stereo images in the 21st century. All these applications involve enhancing the sense of "presence" or "reality" and are often accompanied by enhancements in audio presence as well. Similarly, high definition TV (HDTV) is another related technology, and it is obvious that stereo TV is being viewed as the next step beyond HDTV. NHK estimates that in 1990 there were about 80,000 viewers of HDTV in Japan but that the number would be 10 million by the year 2000. It is also not surprising that research in "virtual reality" (VR) is associated with stereo imaging. At the moment, however, VR systems, especially those using helmet-mounted displays, suffer severe limitations due to the poor resolution of their LCD displays. However, imaging applications are also rife in science. In 1982, C. Smith wrote that "future generations will be astonished that for a few decades in the 20th century we were happy to accept these small flat images as a representation of the real three-dimensional world." It seems obvious that in robotics, photogrammetry, pattern recognition, etc., three-dimensional imaging would be a great help.

P. Panabaker from Imax made an interesting presentation about commercial applications of 3D in theaters. Imax is a Canadian company established about 15 years ago with the assistance of the National Film Board (NFB) of Canada. (Those readers who, like me, are film buffs will know that NFB has been at the forefront of film making since the earliest days of cinema.) Imax builds complete theaters and shows films that it produces itself. Almost 2 years ago, I wrote about Fujitsu's 3D computer generated movie at the Osaka Expo'90 (see the electronic report fujitsu.3d, 25 April 1990). This exhibit was created by Imax, which also did the Suntory exhibit (which I did not see.) Panabaker described the care that is required to produce 3D films that are not only very realistic but also comfortable to watch for long periods of time. For computer graphics, Imax generates and records images at 4000x3000 pixel resolution, recorded on separate left and right 70-mm film frames, and has shown such films as early as the mid-1980s. For the Fujitsu exhibit Imax used lesser resolution (2048x1500) but produced 11 minutes of full color, fully shaded rasterized images, with separate film strips for each eye. Each frame required several minutes of computation on VP200 class machines and the project spanned 21 months. The two Imax projectors are huge--each requires more than 15 kW of arc illumination--and project onto a screen 29 meters wide that is specially metallically coated after erection. This kind of technology is still far too expensive to be available in the home, but it is gratifying to see such hi-tech ideas made into successful products.

L. Lipton (StereoGraphics) described the infrastructure necessary for practical use of electronic stereo displays by working scientists. StereoGraphics markets one of the most successful of these. Symposium participants from the West were well aware of this and spoke highly of it, but Japanese attendees were strangely unaware of it. Lipton made another point that in some fields of science, stereo imaging is part of the training and hence professionals in these disciplines use it as a standard tool, cartography being an obvious example. However, in other areas, students and young researchers are not similarly exposed and these people have to be alerted to the possibilities. I admit to being persuaded by this and feel that there are two points here. First, that research in the general area of stereo or 3D imaging will go forward. Second, that it has already progressed to the stage where it is now practical; computers that can generate one view perspective can just as easily generate a slightly different one. Moderately priced systems exist that can convert this to stereo images on most workstations and even many PC monitors, and these can be viewed comfortably by any one of several polarized glass systems, wired or wireless. I believe that scientists now using computer graphics could put these techniques to excellent use immediately. Also useful, but for a different constituency, there are not only stereo slide and print cameras available but a $3,500 Toshiba camcorder as well. (M. Starks pointed out that the Korean Goldstar Company has recently received a patent for a 3D VCR.) All of the above are barely more expensive to purchase and process

and almost as easy to use as conventional products. I think that we could make a substantial improvement to understanding the complex world around us by encouraging the use of the appropriate parts of this technology. (Subsequent to this symposium, Starks wrote to tell me more about the Goldstar prototype TV, which he claims is soon to appear as a consumer item. It has line doubling, edge enhancement, and some other simple tricks to improve image quality. Unlike previous line doublers, this works on a field-by-field basis, so it is 3D compatible. Starks claims that in 2D it was nearly the equal of HDTV and in 3D it was stunning, especially since it is supposed to be available for just a few hundred dollars more than a standard set and is 100% compatible with all existing video hardware and software. Starks feels that the effective bandwidth of the monitor is about 40 MHz.)

In Japan, work in stereo and 3D imaging spans the same broad subfields as in the West except that there is a decided difference in emphasis. (At the symposium, Starks (3D TV) noted that most of the relevant information is not given either as journal or conference papers but rather in patent applications. In his paper he presents over 500 cited patent references to substantiate this point. Luckily, the Japanese patent system is the world's first to be computerized and researchers can now access this information from anywhere in the world.) In Japan, there is much more research than in the United States on the study of stereo and 3D in concert with high definition TV and somewhat more than in the EC. This is natural as both Japan and the EC have HDTV products that are either on the market or nearly so. What is somewhat surprising, though, is that the Japanese are also much more active in research concerning autostereoscopic and glassless imaging, and especially research connected with lenticular sheets. A main motivation seems to be related to video conferencing, where it is felt that having all the participants view each other with glasses would be very unnatural.

The basic idea in this approach is also not new. An object is photographed with two cameras corresponding to left and right eye. Then images are displayed on a sequence of narrow vertical stripes, left eye image, right eye image, left, right, etc., a corduroy or interdigitated display. These days flat panel display devices are often used for the displays. Immediately in front is an array of half cylindrical lenses roughly matching the pitch of the display. Out in front of all this sits the observer, who can have an authentic stereo image if he/she is positioned in exactly the right place. As mentioned above, little head movement is possible and the observer must be seated at exactly the right position. Multiple observers can view this kind of display at the same time, although each observer must be correctly positioned. Also it is possible for observers to get a pseudostereoscopic image (right image to left eye, and left to right).

It is also possible to interdigitate more than two images, and this reduces the observer positioning problem, although it also decreases the resolution capability of the display devices, a problem with pixel-based displays, less so with fully optical displays. NTT incorporates an "eye-tracker" to follow the observer and interchanges the views from the lenses if a pseudostereoscopic view would be observed, but this makes it more difficult to use with more than one observer. At the University of Tokyo, Prof. Hamasaki's group has been working with images based on two Fresnel lenses and 24 prisms in order to make large color photographs. Care is required to produce these, but in the examples I saw, the stereo effect is exceptionally realistic and the resolution is as good as in normal color television. Viewers can move their head about 10 inches left-right allowing a great deal of look around, and viewing distance can vary over several meters.

Hamasaki, the symposium director, has been working in the area of 3D imaging for almost 30 years and, in fact, will be retiring from his current University of Tokyo position in March 1992. In addition to the photographic project mentioned above, his laboratory is filled with other interesting experiments associated with autostereoscopic imaging. One of the most careful involves a multiplano lenticular display that interdigitates eight views behind a lenticule, using an array of eight solid-state sensor cameras mounted on a base and viewing through a large Fresnel-type optic into a CRT. Using eight (rather than two) cameras increases the viewing zone, allows the observer's location to be less critical, and provides some look around ability. But the image is still limited in the number of observers that can view it. Hamasaki is hoping to increase the size of the system to 20 cameras. There is a continuing resolution problem because the flat LCD requires one pixel red-green-blue (RGB) set for each camera. There are also promising experiments on projection systems using arrays of LC panels. Considering the variety of projects, the laboratory is doing very impressive research. Symposium participants felt that there were few places in the world engaged in comparable work; however, one observed that the group needs at least five times the resources available to it in order to make timely progress.

The Heinrich-Hertz Institute in Berlin is also doing very advanced work in the design of lenticular screens and applications to glassless 3D systems. R. Borner presented a summary of these projects, which have been going on for more than 7 years. They are currently experimenting with an 18-channel front projector and hope to increase this to 24 channels, and they are also working on two rear projection systems, one

with a 640x480 pixel LC overhead projection panel in 8 grayscales and the other with an 18-inch direct view electroluminescent (EL) display with 16 grayscales and 1024x864 pixel resolution. To the best of my knowledge, the Borner group's work designing screens with varying pitch corrections is the most advanced anywhere.

Several of the U.S. participants at the symposium were surprised at the amount of work going on in Japan in the area of glassless autostereoscopsis. (Except for Benton's holographic work at MIT, there was not much reported from the United States on this topic.) All researchers would like to dispense with glasses, but most believe that practical systems will require them for the remainder of this decade. At the moment, the main problem with practical autostereoscopic systems is that the viewing position can be critical. One American remarked to me that he *didn't understand* why there was so much interest as there seemed to be major technical problems and, in fact, there might even be a wall that could not be breached. Another commented that he found the difficulties encountered when moving from viewing lobe to viewing lobe (i.e., head movement) in glassless lenticular systems to be far more problematic than properly presented glasses approaches. A third said that he saw no Japanese systems that were anywhere near being productizable and some that were much more than a decade away.

Two Westerners expressed serious concern that many of the scientists they met from Japanese companies (especially the younger ones) had huge gaps in their knowledge of what had already been done, and that a number of things were being worked on from scratch again, albeit with new materials. For example, one attendee commented to the authors that the NTT eye-tracker (above) had been done at Hewlett-Packard 10 years ago.

I was surprised to hear this criticism, as one of the only basic books on this topic was translated into English in 1976 from the Japanese edition (1972) and is widely known here.

Three Dimensional Imaging Techniques
by Takanori Okoshi
Academic Press 1976
(Japanese book: *Sanjigen Gazo Kogaku*, 1972)

My own view is somewhat different. The problem of stereo or 3D imaging is old enough that many fundamental ideas have already been proposed. Some of these may have failed in the past because the implementation technology was not up to the demands placed upon it. But it may be appropriate to look more carefully again. Good examples are recent research prototypes by NHK, one of a 50-inch autostereoscopic 3D display using a 1.5 M x 3 pixel projector (1440x1024 resolution) and an air-filled lenticular screen and the other a 9-inch 3D electroluminescent display. Also, Hamasaki's photographic work clearly indicates that the viewer positioning problem can be solved, or very significantly reduced. Even in the case of restricted viewer position, there are obvious applications, such as sitting in front of a computer monitor looking at the image of a molecule. Also, the interest in video conferencing is very great in Japan. As one participant put it, you can have a successful company selling shutter glasses, or you can make real money designing video conferencing for businesses. Finally, whoever said that the Japanese were daunted by 10-year time frames?

At least one speaker H. Tilton (Visonics) disagreed with the claim that 3D HDTV was far away. He felt that a very modest increase in HDTV channel space compared to 2D transmission was all that was needed, and that if an appropriate standard was adopted a wide variety of receiver designs as well as compatibility with 2D systems could be achieved. Tilton's idea is to transmit one 2D HDTV signal, and another signal describing depth, which he claims can be done with a bandwidth of about one-fourth that of the luminance signal. However, it was clear that most attendees felt that bandwidth was a serious problem and that related work on image compression was very important.

Several interesting symposium sessions were devoted to applications of 3D to other disciplines. These included analyzing electron micrographs of GaP_{1-x} for dislocations, medical endoscopy, nondestructive investigation of animals' internal organs, etc. There was a paper by Sony researchers on an almost commercial stereolithography system (largest size, 1 meter), although frankly this only had a very weak connection with other aspects of this symposium. One of the most impressive medical applications was from researchers at Chiba University Hospital, whose goal is to provide a tool "with which many doctors can, with their own eyes, simultaneously and clearly observe a 3D diagnostic image of an object organ from any direction which is selectable and controllable by the doctor's hand." For some years the stereoviewer has been available for use with angiographic images, but these cannot be viewed by several doctors simultaneously. Similarly holographic images are sometimes used, with all their current difficulties. Of course, 2D displays of synthesized computed tomography (CT) and magnetic resonance imaging (MRI) slices are also widely used. The Chiba experiment uses x-ray images recorded on a video tape or 8-mm camera. Images are generated via a total circumference radiograph system (circa 1982) that can take 240 images in 8 seconds over 360°, i.e., with a 1.5° pitch. The current system takes these images, enhances them, and makes them available 12 at a time in a frame

buffer, which then displays them via a CRT with lenticular screen with 1 mm pitch and 12 dots per pitch (corresponding to 18 degrees of rotation). The authors are hoping to improve the system in the future, but they note that a major difficulty is that there are no currently available flat lenticular glass sheets installed within the glass envelope of a CRT and that they are looking into using LCDs.

One of the most obvious applications of 3D is to remote sensing, photogrammetry, and geographic information systems. S. Murai gave an exciting paper of what can be done, automatically, from digital elevation models (DEMs). DEMs can be obtained from stereo aerial photography, stereo space imagery, and rasterized contour maps. Each of these requires different technology and Murai listed various projects that groups in Japan have been working on. For example, image matching (which is needed for aerial and space images) is being studied by the Japan Society of Photogrammetry and Remote Sensing, a research committee set up by MITI, the Japan Highway Corporation, the Geographic Survey Institute, etc. The key to progress in this area is how to automate the digital data. While not discussing any details of this work, Murai gave several fascinating practical examples including DEMs generated automatically by image matching of stereo aerial photos and then used for a highway plan, 3D drainage maps generated automatically, a bird's eye view of a shaded hillside in Bhutan obtained by processing an input contour map, a 25-second 3D animation "flying" along a fault line in Shikoku Island and, finally, a "fly-by" of Mount Fuji. I think that everyone in the audience was very impressed with the fact that this could be done essentially automatically, as well as with the information content of the images.

When I wrote about virtual reality last year (see reference above), I mentioned work by S. Tachi (University of Tokyo). Prof. Tachi showed a very impressive movie at the symposium based on research done over more than 10 years in Japan. His work has focused on developing anthropomorphic robots that will work in synchrony with a human (so-called master-slave system). The operator, using a helmet and data glove, moves around and the remote robot duplicates his movements. (This concept is not new, but Tachi's work seems to be one of the best implementations.) The weight of the visual display is carried by a link mechanism with six degrees of freedom, which cancels gravitational force by use of a counter balance mechanism. The master arm has 10 degrees of freedom; 7 degrees of freedom are allocated for the arm and an additional three are used to comply with the body movement. The operator has input to his goggles not only from TV, etc., mounted on the robot, but also from integrated computerized displays that allow him to "see" what the robot is seeing even if the robot's vision is obscured, for example, by smoke. Thus, this system assumes a known environment to work in. We watched a demo of the robot lifting eggs from a basket as well as turning off a valve in a smoking room. The most interesting aspect of this demonstration was that Tachi assured the audience that the operator needed no training to use the system because it operated very naturally. He put it more dramatically: operators already come to the system pretrained by living.

The "art" portion of the symposium was provided by J. Gjessing (Norway), who demonstrated various aspects of his anaglyphic slide work. Conference attendees also had the opportunity to learn about "virtual drugs" at an evening session. I don't think that any of the Westerners attended.

TOURS

As part of the Symposium on 3D Imaging Technology and Arts, the organizers arranged for foreign participants to visit four laboratories in the Tokyo area to see representative work in this field. Visits were short and focused. The description below is meant only to give a rough sense of what we saw and put it in perspective.

NHK Science and Technical Research Laboratories

This laboratory celebrated its 60th anniversary in 1990. Three hundred twenty people (270 research staff) are working in three general areas related to broadcast engineering. The annual budget is about ¥7.7B ($62M), approximately 1.3% of NHK's total budget. General research thrusts are as follows.

- Putting new broadcast media into practice. In August 1990 the third Japanese broadcast satellite was launched, BS-3. HDTV is being transmitted from this 8 hours each day as well as some data-broadcasting. NHK has been working on HDTV since 1964 and demonstrated a stereo HDTV system in 1989. We were told that there is no plan yet for a commercial product, but one is expected soon. Broadcasting equipment, transmission systems, and home receivers are studied at the laboratory. Currently it is possible to purchase for home use a 50-inch HDTV monitor for about $25K (in Japan this is called High Vision TV) that will allow viewing of prerecorded tapes from a VCR or viewing of decoded signals from the satellite. However, the satellite signals need to be decoded. At the moment this requires another box (MUSE decoder) about the size of a VCR, about $10K. We were told that an

implementation via large scale integration (LSI) was in progress. The laboratory is also working on a 33-inch, wall-mounted, plasma discharge panel (6-mm-thick) HDTV display and is heavily involved in studio and international standards.

- Improved conventional broadcast services. Better reception, noise and interference reduction research, such as optical cable TV. Work on machine translation (as well as some speech and pattern recognition), which is already in use for making subtitles for news programs. New cameras for use under a very wide range of light (sunlight to starlight) and wireless (45-GHz) broadcast cameras. Experimentation with synthesizing HDTV and real-time images using "chromakey" (see also discussion of Sony below). There is also a very interesting experiment with digital broadcasting that allows use of 35- to 40-cm-diameter antennas for nearly all of Japan reception and even mobile reception.

- Research into future broadcast systems. Materials for signal processing, recording, display, and LSI are studied. Also ISDB, Integrated Service Digital Broadcasting, the satellite equivalent of ISDN, which will allow broadcasting of TV, audio, fax, software (data), telemusic, etc., as well as 3D video and audio are major projects.

We saw several examples on enhanced reality work at NHK. One was a wall of 160 small speakers that could be driven at appropriate phases so that the sound appeared to emanate from a point several meters in front of the wall. NHK scientists told us that they could also localize (in space) different kinds of sounds, such as different instruments. This type of research has been done in other places. The difficult part is how to encode all the different phase information on a tape or disk and then distribute it to the speakers properly. We did not have any opportunity to discuss this aspect. We were given a demonstration of field sequential stereo HDTV based on film (not computer generated). In principle this is fairly direct, but the implementation details are difficult and NHK pulled it off very well. Everyone was impressed with the visual effect; brightness, clarity, and depth were excellent. In fact R. Kroiter, who is one of the founders of Imax, commented that the apparent resolution was even greater than what he normally expected even from HDTV. (See also the remark by Starks above about information content in stereo images.) We were shown a demonstration of the autostereoscopic system based on a 50-inch lenticular projection system. The resolution is not as good as the HDTV system, and viewers had to be carefully seated, but no glasses were needed and the image was amply bright and clear.

One of the most interesting demonstrations (and the furthest into the future) was by Mahito Fujii in the Visual Science Research Department. Fujii's work is directed toward developing a fully 3D image beginning with only two or three static 2D TV pictures. The resulting 3D image can be rotated (a little). In other words, occluded information is interpolated as needed. His approach is to use the fact that edges probably have the same orientation in the two images. He has built a four-layer neural network to extract binocular disparity by the use of edge information and the model can specify relative positions in 3D space that can then be interpolated to form textured surfaces. Fujii admitted that this was still in the very early stages; his neural model runs on NHK's Convex, much slower than real time. (I was told that there is also related work at the Heinrich-Hertz Institute in Germany.)

The final tour stop was a standards laboratory, where a set of "standard" HDTV still pictures was being investigated for various characteristics such as color, sharpness, etc. Standard moving images have not yet been selected. Our host at NHK, who also presented a paper at the symposium summarizing the company's work, was Dr. Hideo Kasaka.

Matsushita Electric Works

This virtual reality exhibit was one small part of a large public exhibit area where many of the company's consumer products were on display including such low-tech ones as light bulbs. The VR system incorporated a conventional head-tracker, goggles, data glove, and stereo headphones. As usual with these systems, the LCD resolution in the goggles was not as good as one would like, although it was about as good as one normally sees. Also, several of the participants complained that the stereo video effects could be done better and that the attendant who moved around their hand was too intrusive. Nevertheless, the most interesting part of this demonstration was that it was included as part of a kitchen planning system. The user is placed inside a kitchen that he/she can walk through and, by moving the data glove and "grasping," can open cabinets, turn on faucets, radio, etc. Carping from the experts aside, I thought that it was a good demonstration and will be effective as a sales tool. Matsushita claims that it is the first commercial application of VR.

Sony Media World

We spent one afternoon at Sony's public display area in which a large number of its fanciest products and prototypes were on exhibit. This included a multipurpose teleconferencing room, HDTV displays (both 2D and field

sequential), and an extremely sophisticated intelligent TV studio where just about every digital processing technique was available from within a "video-cockpit" to control production, editing, and transmission. This included chromakey, converting 2D images to 3D, and others. In the stereo TV demonstration we were shown two films composed of still photos of Japanese museum pieces and a third (much more effective) showing a training film for ophthalmic surgery. The latter revealed just how helpful the sensation of depth can be in transmitting information. In both this demo and in NHK's, it was pointed out just how difficult the photographing of multiple images can be and how much care must be exercised during all steps of the process. Sony's exhibits, like Matsushita's, covered much more than we were able to see during one afternoon.

INTERNATIONAL CONFERENCE ON SOLID STATE DEVICES AND MATERIALS (SSDM '91)

This article reports on the highlights of the 1991 International Conference on Solid State Devices and Materials, held in Yokohama, Japan, during 27-29 August 1991. In addition to covering key technological areas in silicon microelectronics, this year's meeting featured six special symposia dealing with Large-Area Integrated Electronics, Ultra-Clean Processing, Surface Engineering for Semiconductor Nanostructures, Advanced Materials for Giga-Scale Integration, Advanced Optoelectronics, and Superconductor Technology.

by S. Ashok

INTRODUCTION

The International Conference on Solid State Devices and Materials 1991 (SSDM '91) was held at the brand new Pacific Convention Plaza, Yokohama, Japan, during 27-29 August 1991. Initiated in 1969 as an annual domestic meeting, this conference has progressively gained in scope with its becoming international every third and subsequently alternate year. In view of the ever-widening influence of the Pacific Basin in micro- and optoelectronics, SSDM has since 1990 become an annual international meeting with considerably increased overseas participation. As Prof. Nannichi, the Organizing Committee Chair, pointed out in his welcoming address, SSDM has also, over the period, spawned numerous specialists' conferences in Japan. Despite extensive screening of abstracts submitted for this year's SSDM, there were about 220 presentations, with a quarter from overseas and half of the total in poster sessions. The meeting had a total attendance of about 850, below the all-time record of over 1,000 last year.

This year's conference was organized around specially chosen symposia, along with some selected topics of current technological interest. The featured symposia topics are as follows:

1. Giant Microelectronics
2. Science and Technology on Ultra-Clean Wafer Processing
3. Surface Engineering for Semiconductor Nanostructures
4. Advanced Materials for Giga-Scale Engineering
5. Advanced Optoelectronic Devices
6. Material Design and Device Application of Superconductors

In the following, we describe the most salient developments reported in the various symposia along with our perception of where the respective fields are heading and where the most intense interests are currently focused.

GIANT MICROELECTRONICS

"Giant Microelectronics" is no oxymoron but a colorful--and quite appropriate--title chosen by the conference organizers for the upcoming area of large-area (meter-scale?) electronics that nevertheless has as its component parts micron-scale devices. This area tends to address the important topic of matching the ever-improving performance and miniaturization of computers with corresponding enhancements in the human-computer interface. The principal ramifications of this field are (1) eventual eclipse of the cathode ray tube (CRT) as the high-quality display device; (2) improved levels of portability as well as user friendliness of displays; and (3) the increased use of polycrystalline and noncrystalline thin films for active device applications, albeit at slow operating speeds compared to their crystalline bulk counterparts. Requiring massive investments, but having enormous market potential due to the end-use in both computers and TV, this technology is clearly impelled by the strong thrust provided by Japanese concerns. This fact also was reflected in the dominance of papers from Japan.

The key element of giant microelectronics is the thin film transistor (TFT), which serves as the active matrix switching element. The main contenders for the active semiconductor material are poly-Si and hydrogenated amorphous Si (a-Si:H). The major problem

areas in this technology are depositing uniform semiconducting thin films over large areas, developing the necessary tools for deposition and further processing, improving the film electronic properties such as carrier mobility, keeping a high aperture ratio as pixel size is reduced, and reducing the overall process temperature so that low-cost substrates can be used. In a lead-off invited talk by H. Oshima and S. Morozumi of Seiko-Epson, the features of low-temperature (<600 °C) deposited poly-Si for high-resolution, high pixel density applications such as high definition TV (HDTV) valves (projection displays) were outlined. Their conclusion was that a-Si:H TFTs could be appropriate for large-area displays, but that poly-Si with its much higher mobilities and better device performance was essential for high-resolution liquid crystal display (LCD) applications. In follow-up poster papers, Seiko-Epson researchers also described poly-Si TFTs fabricated by using solid phase crystallization of very thin amorphous Si films and by XeCl pulsed excimer laser annealing of low-pressure chemical vapor deposited (LPCVD) poly-Si. The former technique is easily scaled up for production and yields films with carrier mobilities greater than 20 cm^2/V-s without the need for hydrogenation and TFT on/off current ratios greater than 10^7. The laser anneal technique, while still experimental, yields electron mobilities of over 180 cm^2/V-s and hole mobilities of over 60 cm^2/V-s, thereby offering the possibility of selectively laser annealing sections of the film for the high-current driver TFTs and forming the matrix switching TFTs on the as-deposited sections with the corresponding low off current.

There were other papers demonstrating the efficacy of laser-annealed poly-Si TFTs. A group from NEC Corporation reported carrier mobilities similar to those of Seiko-Epson, and they had fabricated a 640-bit complementary metal-oxide semiconductor (CMOS) shift register data driver operating at 1 MHz. Sony reported controlled grain growth by excimer laser anneal, leading to high carrier mobility as well as low leakage current (<0.02 pA/μm). They attributed their TFT performance enhancement to improved crystallinity in grains and reduced grain boundary trap density. Suggested applications include integrated stacked SRAMs and LCDs built on low-melting-point glasses. M. Matsumara and coworkers from the Tokyo Institute of Technology presented work on a ramp-mode hydrogen radical beam annealing of laser-crystallized poly-Si and found electron mobility as high as 220 cm^2/V-s. The importance of atomic hydrogen for grain boundary passivation in poly-Si has long been recognized by the TFT community and is believed a viable fabrication step in production. It is interesting to note that this contrasts with the general opprobrium extended to hydrogen in crystalline Si, despite a great deal of recent advances in the basic understanding of H in crystalline semiconductors. Of course, there is no room for controversy in the case of a-Si:H, since H is essential for its use as a dopable semiconductor. The Tokyo Institute of Technology group also demonstrated the efficacy of hydrogen radical annealing on hot-wall CVD-deposited *amorphous* Si TFTs. Another paper in the symposium dealing with H in poly-Si was that from Hiroshima University proposing a charge-pumping method for evaluation of the hydrogenation effect in poly-Si TFTs.

The Giant Microelectronics symposium also addressed alternatives to LCD materials used in the standard twisted nematic mode, where associated polarizers limit transmittance of the light valves and are heated by absorbed light. M. Yuki from Asahi Glass Company gave an invited talk on the use of an LC/polymer composite (LCPC) material that operates in a scattering mode requiring no polarizers and at low driving voltages (6 V rms). Based on the LCPC they have fabricated a full-color projection TV with a utilization efficiency of incident light about four times that of conventional twisted nematic-based systems. Yet another use of polymers, this time as the *active semiconductor TFT material,* was reported in a presentation from Mitsubishi. While the best electron mobility (0.02 cm^2/V-s) of this material is still an order of magnitude below that of even a-Si:H, the spin-coated polymeric semiconductor [poly(2,5-thienylene) vinylene] offers potential for low cost and processing simplicity.

An alternative to the (three-terminal) TFT as the matrix switching element in LCD displays is a two-terminal nonlinear resistor. The latter does, of course, suffer from the inevitable absence of isolation between the drive and output signals but offers advantages such as no crossovers, no storage capacitor, fault tolerance, and fewer masking steps. K.E. Kuijk of Philips, Holland, presented an invited talk on the application of a-Si diodes for a full-color 6-inch TV display. He described a novel double diode plus reset circuit that has the same number of connections as a TFT active matrix LCD. Another two-terminal approach to the switching device was described by researchers from Toshiba who used metal-insulator-metal (MIM) structures based on anodic oxidation of a Ta thin film.

An innovative giant microelectronic technology using gravure printing techniques was presented by a group from Matsushita. Using glass intaglio and a silicon rubber roller, they were able to fabricate fine patterns on large areas (60 x 230 mm) with 10 μm accuracy for use in a thermal printing head. Other papers presented in the symposium included a catalytic CVD process for poly-Si deposition at 410 °C [Tokyo

Institute of Technology], low-temperature operation of poly-Si TFTs [Hiroshima University], and study of a noncrossing TFT matrix [Fujitsu]. A. Chiang et al. from Xerox, Palo Alto, reviewed in an invited talk the correlation between material preparation and processing parameters of poly-Si with the electronic properties of the active layer. She also addressed the role played by impurities in the crystallization process and the leakage mechanisms.

In summary, the symposium on Giant Microelectronics reflected the importance given to this area by the Japanese companies, spanning a wide spectrum beyond conventional micro- and opto-electronics. No major breakthroughs in terms of concepts or phenomena were reported, but the strong strides made in technology development were evident from the presentations.

SCIENCE AND TECHNOLOGY ON ULTRA-CLEAN WAFER PROCESSING

This symposium was intended to focus attention on the extreme necessity of contamination control as microelectronics "inches" towards nanoelectronics. The opening invited lecture was given by Prof. T. Ohmi of Tohoku University, who has been a pioneer in promoting and developing techniques for the preparation of ultra-clean surfaces characterized by the absence of particulates, organic and metallic contamination, native oxide, molecular adsorption, and surface microroughness. He stressed that such extremely stringent surface preparation steps are essential for establishing high-performance, low-temperature Si processing. In his presentation, he showed the influence of pH control of cleaning solutions on particle adhesion and surface microroughness. The role of particulate contamination on MOS interface properties is well known, but surface microroughness was shown to be equally deleterious in terms of channel mobility reduction and MOS charge to failure. Ohmi also discussed the need to maintain the Si surface cleanliness and to activate a growing film on Si by using very low energy ion bombardment. Such an approach was reported to give nonalloyed Al/n^+-Si ohmic contacts with lower contact resistance than the conventional air-exposed process, Cu/Si Schottky diodes of near-ideal characteristics, and Cu interconnects with electromigration lifetime enhanced two to three orders of magnitude. In another invited paper given by Prof. C.R. Helms of Stanford University, it was pointed out that the chemistries for metal removal are strongly dependent on the Si surface chemistry (e.g., surface pretreatment step prior to metal incorporation) and the chemical environment of the metal impurities. The cleaning issue was further addressed by B.E. Deal et al. of ADVANTAGE Production Technology, Sunnyvale, CA, who described a single-wafer HF/H_2O vapor cleaning system that yields better quality MOS interfaces compared to conventional aqueous cleans. Such "dry cleaning" systems are presently coming into vogue for environmental reasons (much less use of chemicals) as well as ready adaptability to cluster-type integrated processing.

An IBM effort in hydrogen fluoride (HF) and ultraviolet (UV) ozone-integrated wafer cleaning was described in an invited talk by M. Liehr and S.R. Kasi. Their results show that foreign chemical species present at the surface in submonolayer levels can profoundly affect the quality of subsequently grown SiO_2 and hence the MOS parameters such as breakdown field, interface trap density, and radiation sensitivity. Their conclusion was that establishing correlations between detailed process chemistry and resulting device parameters is essential to understand, predict, and control molecular contamination in future ultra large scale integration (ULSI). HF-treated Si surfaces were also discussed in other papers. An x-ray photoemission spectroscopy (XPS) study by Prof. M. Hirose's group in Hiroshima University extended previous work on H-terminated and F-terminated Si (111) surfaces and showed that suitable buffering of the HF solution was essential for obtaining a step-free, atomically flat surface that is chemically stable. A scanning transmission microscopy (STM) study of HF-treated Si (111) by researchers at the Electrotechnical Laboratory revealed that a sample treated in 1% HF shows the SiH_3 phase, while a follow-up boil in hot water changes it to the SiH phase. This was verified independently by researchers from Fujitsu, who used infrared (IR) absorption spectroscopy.

The influence of contamination, passivating species as well as process-induced (plasma/ion bombardment) damage on that most precious of all interfaces, viz, Si/SiO_2, and the p-n junction was addressed by a number of papers in this symposium. Y. Ono et al. from the NTT Atsugi Laboratories presented some very interesting new results on thermally diffused fluorine in SiO_2. From Auger electron spectroscopy (AES) and secondary ion mass spectroscopy (SIMS) measurements, they found that the F-profile (obtained from an F-implanted layer) into SiO_2 sharply peaked at the Si/SiO_2 interface and *abruptly dropped off inside Si.* From electron spin resonance (ESR) measurements they also found the trivalent Si dangling bond density (Pb center) to fall with increasing F-dose, thus confirming fluorine passivation of the silicon/oxide interface traps. K. Machida et al., also from the NTT Atsugi Laboratories, presented an elegant technique for estimating charge buildup on gate oxide during plasma processing. Their method is based on the observation

that the oxidation of a metal film on SiO_2 is dependent on the electric field set up by the electrons diffusing from the SiO_2 surface to the metal. The latter, in turn, depends on the radio frequency (RF) bias, and they were able to correlate the gate oxide yield directly to the metal (Mo) oxide thickness measured by ellipsometry. Ohmi's group at Tohoku University also addressed the question of contamination in conventional ion implantation systems. They found that metal atoms in quantities on the order of 0.05% of the total dose are incorporated into ion-implanted wafers. With carefully installed sputtering protection boards, they were able to reduce the metallic contamination by a factor of 3. This directly translated into reduced p-n junction leakage under the desired low-temperature (<600 °C) post-implantation anneal. Using topographic, thermal wave, and atomic force imaging, researchers from Toshiba concluded that surface microroughness severely affected VLSI yield and reliability through oxide film degradation.

SURFACE ENGINEERING FOR SEMICONDUCTOR NANOSTRUCTURES

This symposium dealt with a number of topics concerning semiconductor surface passivation, heterointerface control, and atomic-scale characterization of interfaces. In a lead-off invited talk, F.J. Grunthaner of the Jet Propulsion Laboratory (JPL) reviewed atomic-scale characterization and control and synthesis of semiconductor surfaces and interfaces. He described the features of strained layer epitaxial interfaces evaluated by a variety of techniques and emphasized the importance of interfacial roughness on superlattice systems. T. Saitoh et al. from Hokkaido University described a new technique to determine the surface state density of semiconductor surfaces by band-edge photoluminescence efficiency measurements. They showed examples of sulfur passivation of GaAs surface and the use of a silicon interface control layer between SiO_2 and InGaAs. An alternative approach to surface state measurements was described by K. Hirose et al. from NEC Fundamental Research Laboratories. By using photoemission yield spectroscopy, where the resolution is limited only by the monochromator used (to 0.01 eV), they were able to demonstrate the changes in surface state density and distribution with surface preparation conditions.

In another invited talk on atomic imaging, atomic processing, and nanocharacterization, L.L. Kazmerski of the U.S. National Renewable Energy Laboratory (NREL, formerly SERI) described the application of STM to generate patterns using lithography as well as to etch and to pattern surface structures. Nanoscale in-situ electrical characterization was also shown possible with the STM electron probe to map the minority-carrier current and conductivity variations. He showed "graphic" STM images of $CuInSe_2$ (a leading thin film solar cell material) before and after "nanoprocessing" with oxygen, followed by nanoscale electron beam induced current (NEBIC) response of $CuInSe_2$ grain boundaries with and without oxygen passivation. Carrying the work further, he showed the possibility of atomic-level engineering using a 3- to 5-mil-diameter catheter wire tip to introduce oxygen gas onto the surface. Using twin catheter tips, one for imaging and the other for atomic processing, he presented exciting results on the first atomic engineering on a semiconductor surface. The process makes possible (1) identification of specific atoms to be removed from the surface; (2) the removal of such atoms; (3) the placements of individual, extrinsic atoms at those locations; and (4) comparison of the results on a bulk basis (using conventional EBIC) and on the nanoscale using NEBIC. Certainly, such atomic-scale processing plus characterization opens up spectacular opportunities in a number of areas including semiconductor surface and grain boundary passivation, as well as atomic-scale defect engineering.

A different type of nanoscale processing technology using STM was described by researchers from Hiroshima University. By pulsing the negative bias on the STM tip in different ambient gases, they were able to form holes 25 Å in diameter and 7 Å deep and carbon dots 8 Å in diameter and 7 Å deep. Selective *epitaxial* growth of GaAs and AlGaAs to form quantum dots in a metal organic CVD (MOCVD) system was reported by a University of Tokyo group. Using in-plane atomic migration and changes in growth rates of the crystal planes, they were able to develop a novel technique for fabricating one-dimensional weakly coupled quantum dots and GaAs dots surrounded in three dimensions by AlGaAs. A selective growth technique for GaAs molecular beam epitaxy (MBE) at growth temperatures as low as 550 °C was demonstrated by T. Sugaya et al. from the University of Tsukuba. By irradiating the growth surface with atomic hydrogen, they were able to enhance the Ga and As desorption rate from the SiO_x or SiN_x masking surfaces, thus improving the growth selectivity.

Selective-area epitaxy and pattern formation in III-V semiconductors through UHV processing for two- and three-dimensional nanostructures was also addressed in an invited paper by Y. Katayama et al. from the Tsukuba Optoelectronics Technology Research Laboratory. They described an ultra-high vacuum (UHV) processing system with in situ electron beam (EB) lithography, EB-induced Cl_2 etching of GaAs, and selective-area growth of GaAs using an SiO_2 mask. Lateral epitaxy [by metal organic MBE (MOMBE)] on *maskless*, patterned GaAs substrates was described in a paper from another group in the same laboratory. By suitable control of growth conditions, they were able to confine

the growth to the sidewall. This technique is clearly attractive for advanced device structures such as those based on quantum wires.

Chemical treatment of compound semiconductor surfaces has attracted a great deal of attention ever since the demonstration a few years ago that simple aqueous S and Se treatments of GaAs can be remarkably effective in passivating nonradiative defect centers at the surface. This, in turn, reduces the surface recombination velocity for excess carriers and improves the performance of minority-carrier devices in practical devices such as bipolar transistors and solar cells. These results also spawned interest in the study of such chemical passivation steps at metal-semiconductor (Schottky barrier) and semiconductor heterojunction interfaces, both from possible applications in interfacial electrical barrier control and understanding the nature of interface Fermi level pinning. A good part of this symposium was hence devoted to this topic of surface/interface passivation. In the lead invited talk on this topic, C.G. Sandroff of Bellcore provided a review of the S and Se passivation results on GaAs, followed by recent results on reliability enhancement of InGaAsP laser diodes (under electrostatic discharge) under such surface chemical passivation. By using in situ photoluminescence (PL) in an MBE chamber, he showed it is possible to gain new insights into the passivation mechanism, e.g., which type of surface reconstruction is best for reducing surface recombination. Sandroff further pointed out that the in situ PL probe (through the dependence of PL peak on temperature) offers the bonus feature of measuring the substrate temperature. Precise measurement of wafer temperature during processing has always been a tricky problem, and this PL-based technique is currently being developed for incorporation in plasma processing and other equipment.

There were a number of papers dealing with surface/interface passivation of III-V semiconductors. O.S. Nakagawa et al. from the Pennsylvania State University reported on the results of an Au/GaAs Schottky interface modified by a self-assembled monolayer of conformationally ordered octadecyl thiol. They reported enhanced barrier height on n-GaAs with no changes in diode ideality factor, implying the barrier modification is essentially due to modification of interface states and not due to any residual oxide layer. Incidentally, this apparently is the first report of a self-assembled monolayer film formed on any semiconductor. C.G. Choi et al. from Hyundai R&D Center described a forward-bias capacitance spectroscopy technique for Schottky diodes that could be used to evaluate the effectiveness of interface passivation schemes by measuring the interfacial trap distribution. By incorporating a monolayer sulfur passivating film (followed by epi AlGaAs blocking and capping layers) in a surface-emitting, buried heterostructure laser diode, Tamanuki et al. from the Tokyo Institute of Technology were able to demonstrate an order of magnitude reduction in the surface recombination velocity on the sidewall of the active layer.

The application of sulfur passivation to the heterointerface between ZnSe-based II-VI semiconductors [of intense current interest for blue light-emitting diodes (LEDs)] and GaAs was discussed in a paper by T. Ohnakado et al. from Kyoto University. In an interesting new application of the S treatment, they report that the sulfur treatment of GaAs prior to the II-VI growth could improve the optical properties of the II-VI epi material. They also found nearly ideal capacitance-voltage (C-V) characteristics for Au/ZnSe/p-GaAs metal-insulator-semiconductor (MIS) structures, perhaps offering yet another chance for obtaining the ever-elusive GaAs MIS field effect transistor (MISFET).

A novel heterostructure based on amorphous Se on GaAs was investigated by S. Takatani et al. from the Hitachi Central Research Laboratories. The impetus for studying this unusual system stems from the Se passivation of the GaAs interface, coupled with the interesting semiconducting properties of a-Se. They found a staggered band alignment with a small barrier for holes, suggesting potential development of an efficient avalanche photodiode structure (with tunable bandgap if the GaAs substrate is replaced by $Al_xGa_{1-x}As$).

R.H. Williams of Cardiff presented an invited paper that dealt with both heterointerface modification and atomic-scale characterization. He reported on δ-doped InAs/GaAs and Al/n-GaAs interfaces, evaluated by both electrical measurements and by the recently developed ballistic electron emission microscopy (BEEM) technique. He showed that a Be δ-doped layer could increase the interfacial barrier height substantially, just as a Si δ-doped layer could decrease the barrier height.

ADVANCED MATERIALS FOR GIGA-SCALE ENGINEERING

This symposium essentially addressed new nonsemiconductor materials needed to enhance the performance of Si microelectronics as the frontiers are being pushed into the giga-scale integration levels. The materials proposed include those for interconnects, diffusion barriers, high dielectric constant insulators, and contacts.

The first invited paper in this symposium was on plasma-enhanced CVD (PECVD) TiN, given by A. Sherman of Varian Research Center. Sputter-deposited TiN has been found to be highly adherent to Si, while offering

better interdiffusion barrier characteristics than those of the well-established TiW. However, for step coverage over high aspect ratio contacts of via holes, conformal depositions such as from CVD are needed. The ULSI fabrication needs further dictate deposition temperatures below about 700 °C. Sherman presented encouraging results for low-temperature, PECVD-deposited TiN using organometallic precursors. However, the suitability of their process for diffusion barriers and conformal deposition are yet to be demonstrated. An alternative TiN film deposition technique--electron cyclotron resonance (ECR) plasma CVD--was demonstrated by T. Akahori and A. Tanihara of Sumitomo. Using $TiCl_4$ and N_2 as the constituent gases, they were able to obtain Cl-free TiN films with low resistivity (40 $\mu\Omega$-cm), interdiffusion stability for up to 650 °C, 30-minute anneals (for an Al/TiN/Si contact system), and excellent conformality. According to the paper from K. Mori et al. of the Mitsubishi LSI Laboratory, thermal LPCVD of TiN gives excellent contact plug filling capability. Using the same system, they also deposited $TiSi_x$ ohmic contacts prior to the TiN plug deposition.

A low-temperature tungsten CVD process was described by H. Goto et al. from the Hitachi Central Research Laboratories. Using difluoro-silane as a reducing gas additive to WF_6, and surface-reaction-limited deposition at 270 to 395 °C, they were able to obtain conformal W films with low resistivity (10.4 $\mu\Omega$-cm) and minimal encroachment on Si.

The principal new dielectric materials covered in this symposium were ferroelectric thin films. The development of ferroelectric thin films currently proceeds along two fronts: (1) the application of the high dielectric constant in conventional DRAM memory as it evolves to gigabit levels and (2) the ferroelectric hysteresis that offers the exciting possibility of nonvolatile memories, with attendant radiation resistance, high density, and low voltage operation. N. Abt et al. from the National Semiconductor Corporation reviewed the current status and electrical requirements for gigabit level memories. They pointed out that the ferroelectric process is being developed as an addendum to the standard CMOS, so that it could prove versatile enough to be tagged on to different technologies. Sol-gel or sputter-deposited lead zirconate titanate (PZT) is the material mostly used in current ferroelectric memories, and some of the problem areas involve patterning, grain size control, and long-term ferroelectric endurance.

Formation of PZT films by a novel MOCVD process was described by a group from Mitsubishi LSI Laboratory, and formation by a single-target sputtering process was described by researchers from Hitachi Central Research Laboratories. The latter found that precise compositional control was possible by varying the RF power (which controls the Pb content of the film), and they obtained well-crystallized films with a dielectric constant of 1180 after a 590 °C anneal. Another Mitsubishi group reported on a sol-gel synthesis of lead-lanthanum zirconate-titanate (PLZT) films with an order of magnitude reduction in leakage current relative to PZT. They found the equivalent SiO_2 film thickness to reduce with the PLZT thickness and had a value of 0.67 nm for a PLZT thickness of 100 nm.

In a paper by H. Shinriki et al. from the Hitachi Central Research Laboratories, extremely thin films of CVD Ta_2O_5 with a two-step annealing process with UV-O_3 and dry O_2 were reported to have adequate properties as the storage capacitor dielectric in 1.5 V operated 64-Mbit DRAMs. They attributed the improved properties to the control of oxygen vacancies. A novel Si-based alternative to Ta_2O_5 and the ferroelectrics was proposed by a group from the Matsushita Central Research Laboratories. Based on the low leakage current and large dielectric endurance of SiO_2 and high dielectric constant of titanium oxide, they strived to optimize the dielectric by forming a silicon titanium oxide.

The emergence of ferroelectric thin films is quite an interesting development and brings possible integration of nonvolatile memory, a feature unavailable in the days of the nonvolatile ferromagnetic core memory.

ADVANCED OPTOELECTRONIC DEVICES

This symposium was highlighted by an SSDM plenary lecture by T. Ikegami of NTT Optoelectronics Laboratories and a series of invited talks. Dr. Ikegami traced the evolution of fiber optic device performance over the past decade and a half and focused on the laser diode operating wavelength vis-a-vis the optical fiber requirements and the vast reduction in the laser threshold current density. Distributed feedback laser diodes have been commercially used at 1.6 Gb/s rates, and multiple quantum well structures have given extremely narrow linewidths. In the area of detectors, the "Separated Absorption and Multiplication" (SAM) concept with several bandgap-engineered structures has given rise to an excess noise factor as low as 3 and a high gain bandwidth (BW) factor of 90 GHz. Monolithic integration of detector and front-end amplifier is also being widely investigated.

The recently developed Er-doped fiber optic amplifiers (EDFA) have attracted a great deal of attention due to their high current gain at a wavelength of 1.5 μm. This has also resulted in the rush for developing new pumping light sources (laser diodes). Optoelectronic integrated circuits (OEIC) based on InP and planar light wave circuits with patterned SiO_2 waveguides on Si wafers are also being pursued vigorously. The developments in the

field of optoelectronics are ushered in with both the advanced device concepts originating from quantum-size effects and the outstanding developments in material growth.

In the first talk of this symposium, M.E. Prise of AT&T Bell Laboratories described their new developments in free space interchip optical interconnects between integrated circuits. He also appraised the audience on the use of microlasers and GaAs self-electro-optic device (SEED) based modulators in the optical interconnect technology.

T. Kobayashi and B.Y. Lee from Osaka University made a critical assessment of electro-optic (E-O) and opto-optic (O-O) devices and concluded that in order to fully realize their speed potential in the picosecond to subpicosecond range, it is essential to shorten any electrical interconnects. Thus, they favor integration of the total system including the optoelectronic devices.

A review of the physics and technology of quantum dots and wires was presented by K.J. Vahala et al. from the California Institute of Technology. Apart from enhancing the performance of existing devices (e.g., quantum dot lasers), entirely new concepts for process architectures and synthetic dopants could emerge from the physics at zero and one dimension. They also outlined some of the key material fabrication technologies that help realize quantum wires (selective epitaxy) and dots (single-crystal GaAs cluster in the 40- to 100-Å size range). Y. Yamamoto of NTT Basic Research Laboratories and G. Björk of the Royal Institute of Technology, Stockholm, presented their theoretical calculations on microcavity lasers to demonstrate that lasing could occur without inversion. This fascinating result is attributed to a photon recycling mechanism without energy loss. The authors believe that this scheme could open up new possibilities of coherent light wave generation in wavelength regions where population inversion is hard to achieve.

T.L. Paoli and R.L. Thornton of the Xerox Palo Alto Research Center presented a talk on the integration of optical and electronic devices by impurity-induced layer disordering (IILD). IILD occurs because the interface between different III-V alloys is unstable against solid state diffusion of the group III elements in the presence of a high impurity concentration. Thus, under appropriate conditions, it is possible to intermix (without melting) layers whose resultant composition will be an average of those of the initial layers. With lateral patterning on a wafer, lateral bandgap engineering is possible. Si IILD has thus far been applied to low-threshold diode lasers and lateral heterojunction bipolar transistors with exceptionally high gain. The authors believe that the applications will multiply as the IILD technology is refined further.

The characteristics of visible semiconductor lasers based on wavelength shortening in AlGaInP by forming multiple quantum well (MQW) active layers were reviewed by Y. Mori et al. of the Matsushita Semiconductor Research Center. They demonstrated room temperature continuous-wave (CW) lasing at 643.5 nm (bright red) and suggested that orange and yellow CW operation may be on the horizon.

Integrated optoelectronic devices based on organic/inorganic heterojunctions were discussed by S.R. Forrest and F.F. So of the University of Southern California. Organic films, due to their weak Van der Waals bond, can be grown into ordered films on substrates without meeting lattice match requirements. Organic films can also be active semiconductors, thus enabling junction formation and eventually formation of devices based on organic MQWs.

OTHER TOPICS

Besides the above principal symposia, certain sessions were devoted to topics of high technological interest. The following outlines a few of the most striking results presented in these areas.

Hot carrier reliability of metal-oxide-semiconductor field-effect transistors (MOSFETs) under scale-down was discussed in a number of papers. Some of the interesting results are as follows:

(1) 77 K operation to realize higher speed and reliability.

(2) Exponential distribution of trapped holes away from the Si/SiO_2 interface in thin oxide p-MOSFETs.

(3) No x-ray irradiation effect on interface-trap generation during hot carrier injection; of interest with the use of x-ray lithography.

In the area of thin gate dielectrics, reoxidation of the oxynitride was shown to be an effective way of reducing leakage. The practical tunneling limit on the gate dielectric thickness is thought to be around 2.5 nm.

Advanced silicon processing generally focuses on low-temperature epitaxy, low-energy ion implantation for shallow junctions, and an overall reduced thermal budget. Some of the most interesting findings are as follows:

(1) Low-temperature silicon epitaxy without substrate heating, using an ECR PECVD; selective etching/deposition achieved by controlling the H_2 gas addition.

(2) Profound influence of (low-energy) ion flux on the conductivity and mobility of low-T grown Si epi films.

(3) A rapid vapor phase direct doping technique for ultra-shallow junctions (<50 nm), with surface concentration controlled by time, temperature, and dopant gas flow.

(4) Focused ion beam (FIB) etching for micromachining and FIB-induced lateral solid phase epitaxy for eventual three-dimensional integration.

(5) Hot ion implantation (up to 500 °C) into CVD a-Si to increase conductivity.

(6) Cryogenic BF^{2+} ion implantation to suppress defect annealing during implantation and thereby alter fluorine trapping by defects.

The emerging areas of Si nanostructures and heterojunction bipolar transistors (HBT) were addressed in a session on advanced devices. An evening "rump" session also dealt with the latter topic. There were also a few sessions devoted to advances in III-V electron and optical devices, silicon processing, and reliability.

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ASPECTS OF SOLID STATE/ SEMICONDUCTOR PHYSICS RESEARCH IN CHINA

This article describes three laboratories in China that are making substantial progress in engaging current research in various aspects of condensed matter physics: the National Laboratory for Superlattices and Microstructures at the Institute of Semiconductors, Academia Sinica; the Surface Physics Laboratory at the Modern Physics Institute, Fudan University; and the Ion Beam Laboratory at the Shanghai Institute of Metallurgy, Academia Sinica.

by Norman J. Horing

INTRODUCTION

As an academic writing on aspects of solid state/semiconductor physics in China, I feel it is appropriate to open with a few pertinent background remarks. American universities and research laboratories have witnessed the precursor of an important physics establishment in mainland China through the influx of very well trained, diligent, and bright Chinese graduate students, postdoctoral students, and visiting scientists. Starting around 1981, through the efforts of Prof. T.D. Lee, CUSPEA (China-U.S. Physics Examination and Application program) students appeared at our universities, revitalizing the graduate student bodies in physics departments across the nation. The ensuing years brought us non-CUSPEA students whose excellence was also impressive and refreshing. Furthermore, many of us have come to have a keen appreciation of the exceptional talent and depth of knowledge of visiting Chinese scholars at all levels. Behind the strong, beneficial impact that this has had on the American--indeed the world--physics community lies the substantial intellectual power of the Chinese physics establishment. While experimental physics in China may suffer from a lack of expensive, modern laboratory equipment, the strength of the theoretical base is evident in the fine work of the many Chinese students and researchers in China, in America, and throughout the world. Moreover, their dedication is epitomized by the generation of senior physicists who struggled to maintain and improve their skills in the face of the privations of the cultural revolution. The rigors of those times gone by have given way to rigorous classroom training of a new generation of scientists who are fully competent to lead China into the new technological age. As a poor nation with a vast population to support, China has wisely invested its resources in cultivating its ability to "live by its brains." Thus, there stands a fine Chinese physics establishment which, in time, can help to develop Chinese technology toward the point of world competitiveness.

This article is concerned with three laboratories in China that are making substantial progress in engaging important current research in various aspects of condensed matter physics, showing real strength both theoretically and experimentally.

NATIONAL LABORATORY FOR SUPERLATTICES AND MICROSTRUCTURES (NLSM), INSTITUTE OF SEMICONDUCTORS, ACADEMIA SINICA, BEIJING

Research at this well-equipped national research laboratory is focused on semiconductor superlattices and low-dimensional microstructures, encompassing materials, physics, and device standpoints. State-of-the-art fabrication technologies are employed, including molecular beam epitaxy (MBE), metalorganic chemical vapor deposition (MOCVD), etc. Launched in 1986 and re-established in 1989, this laboratory has achieved significant progress in many areas, including theoretical and optical spectroscopy studies of electronic structure, lattice dynamics, optical transitions and energy relaxation of photo-excited electrons in superlattices and quantum wells, quantum transport and other electronic response properties of low-dimensional electronic systems, growth technologies and

material characterizations of MBE-grown superlattices and multilayered heterostructures, and new electronic and optoelectronic devices based on superlattices and quantum wells.

Having twin objectives in the development and refinement of MBE and MOCVD technologies and in the basic physical research on new features of low-dimensional superlattices and microstructures and their potential device applications, this laboratory's principal scientific programs are:

1. Theoretical studies of electronic structures, elementary excitations, and interaction processes as well as transport properties in low-dimensional semiconductor microstructures.

2. Spectroscopic investigations, including conventional/time-resolved photo-absorption and photoreflection spectroscopies, Raman spectroscopy, magneto-optic spectroscopies, etc., used in combination with temperature, pressure, and electric/magnetic field modulation techniques. Research topics consist of energy band structures, intrinsic and extrinsic recombinations, dynamics of photo-excited electrons, and nonlinear optical properties of semiconductor superlattices and quantum wells.

3. Quantum transport (both parallel and perpendicular to interfaces) and its relevance to dimensional size and underlying physical processes.

4. Investigation of electronic properties and behavior of impurities, defects, and deep-level centers related to MBE- and MOCVD-grown materials.

5. Material growth and technologies of various low-dimensional semiconductor structures with artificially tailored band structures.

6. Physical studies of processes underlying superlattice/quantum well based devices.

A tangible representation of research at NLSM is provided in the list of recent research paper titles given in Appendix A.

The principal facilities available at NLSM include:

(a) VAX 3500 computer system.

(b) Time-resolved optical spectroscopy system equipped with synchronously pumped mode-locked dye laser, double-grating monochromator, and 10-K cryogenic refrigerator.

(c) Raman spectroscopic system and photoluminescence spectrometer under pressure.

(d) Modulation/infrared spectrometer composed of monochromator, 10-K cryogenic refrigerator, and detector/computer data acquisition system.

(e) Far infrared cyclotron resonance/magneto-optical spectroscopy system constructed by far infrared molecular laser and 8-T superconducting magnet system.

(f) Different computerized deep level transient spectroscopy (DLTS) junction spectrometers.

(g) 8-T/12-T superconducting magnet system, including 0.3-K He^3 low temperature insert, 4.2- to 300-K variable temperature insert, and computer data acquisition systems.

(h) Molecular beam epitaxy growth systems.

NLSM has about 20 senior researchers and administrators and a total staff of about 40 people. Visiting scientists from all over the world are welcome to work in the laboratory. Limited research grants are available (only to cover the costs of expendable supplies and usage of expensive laboratory facilities involved in research at NLSM). Application forms may be obtained from:

Chief Secretary
Dr. Jian Liu
The National Laboratory for Superlattices and Microstructures
Institute of Semiconductors
Academia Sinica
P.O. Box 912
Beijing 100083, China
Tel: 288131-287 (domestic)
Fax: 86-01-2562389

SURFACE PHYSICS LABORATORY (SPL), MODERN PHYSICS INSTITUTE, FUDAN UNIVERSITY, SHANGHAI

The Surface Physics Laboratory at Fudan University in Shanghai is one of China's prestigious State Key Laboratories. It is dedicated to the study of response and interaction properties of surfaces, interfaces, superlattices, and heterostructures. It is equipped with one MBE machine, with another to be added soon. The major research programs of this laboratory include:

1. Theoretical studies of electronic structures and vibrational properties of semiconductor surfaces, interfaces, and superlattices.

2. Theoretical studies on the electronic properties of metal-semiconductor interfaces.

3. Electron spectroscopy studies of the polar surfaces of III-V compound semiconductors.

4. Molecular beam epitaxy, heterostructures, silicon superlattices, and silicon bandgap engineering.

5. Empty surface states of metals and semiconductors studied by inverse photoemission.

6. Coadsorption study of atoms and molecules on metals and their oxides.

7. New methods used in surface analysis and associated fundamental physics.

For example, some recent theoretical research activities at SPL have addressed the growth properties and phonon spectra of α-Sn/Ge superlattices, geometric and electronic properties of a β-SiC(100) surface; electronic structure of II-VI compounds; alkali metal chemisorption on a GaAs(110) surface; chemisorption of H on a diamond (001) surface; adsorption of alkali metals on a Si(111) surface; electronic structure of Si(111)-surface-adsorbed Al or Sn; effects of surface barrier thickness on electronic states in quantum wells; structure of very thin metal films; and energy band structure of a two-dimensional (2D) lattice of circular quantum dots. Other recent research at SPL is focused on molecular beam epitaxy growth and characterization of Ge_xSi_{1-x}/Si strained layer superlattice systems (including temperature dependence of critical thickness for 2D growth, rapid thermal annealing studies, high-resolution electron microscopy (HREM) studies, Raman spectra studies, Rutherford backscattering, electron diffraction studies, x-ray diffraction studies, and transmission electron microscopy). Moreover, attention has also been given to: SOI (silicon on insulator) systems, boron doping in Si molecular beam epitaxy by coevaporation of B_2O_3, total-current spectroscopy of surface electronic states on Si(100), hot-wall-epitaxy growth of ZnSe and $Zn_{1-x}Mn_xSe$ films on GaAs substrates, etc. A representative list of recent research papers of the Surface Physics Laboratory is given in Appendix B.

The basic instrumentation of the Fudan Surface Physics Laboratory includes:

a. Angle resolved electron spectrometer (VG ADES-400), used with low-energy electron diffraction (LEED), x-ray photoelectron spectroscopy (XPS), angle-resolved ultraviolet photoelectron spectroscopy (ARUPS), high-resolution electron energy loss spectroscopy (HREELS), and a home-made MBE-like growth system.

b. Multifunctional electron spectrometer (VG ESCALAB-5), used with LEED, XPS, Auger electron spectroscopy (AES), ultraviolet photoelectron spectroscopy (UPS), and secondary ion mass spectroscopy (SIMS).

c. Ultra-high vacuum (UHV) electron beam evaporator (Riber SSC), three-chamber system with two electron beam evaporation sources and controller, reflection high-energy electron diffraction (RHEED), quadrupole mass spectrometry (QMS), two thickness monitors, AES, etc.

d. LEED-AES spectrometer (home made), used with a 400-l/s ion pump, a stainless steel UHV chamber, LEED, CWA, QMS, sputtering ion gun, evaporator, and gas inlet line.

e. Ultra-high vacuum photo-acoustic spectrometer (home made), used with a 400-l/s ion pump, cylindrical mirror analyzer (CMA), QMS, CO laser, and PAS signal detector system.

f. Inverse photoelectron spectrometer and total-current spectrometer (home made).

g. Scanning tunneling microscope in air.

h. Hot-wall-epitaxy system.

There are four major research groups at SPL, including a theory group, a molecular beam epitaxy group, a photoemission group, and a new-surface-technique group. (There is also a technician-engineering group.) In all, there are 5 professors, 9 associate professors, 1 senior engineer, and about 7 lecturers, totaling about 22 senior researchers. They also have 5 technicians and about 25 graduate students and several administrators. Further information may be obtained from:

Director Xun Wang
Surface Physics Laboratory
Modern Physics Institute
Fudan University
Shanghai 200433, China
Tel: 86-21-5484906 x2683
Fax: 86-21-3269848

ION BEAM LABORATORY (IBL), SHANGHAI INSTITUTE OF METALLURGY, ACADEMIA SINICA, SHANGHAI

The Ion Beam Laboratory of the Shanghai Institute of Metallurgy addresses the study of interactions of ion beams with solids, as well as ion beam synthesis and modification of materials, micromachining, surface analysis, and other fundamental and applied research. Its importance is partly based on the extensive use of ion implantation in silicon for the production of semiconductor devices and integrated circuits in China (and elsewhere). Current research activity includes low energy ion implantation for the formation of shallow junctions and high energy ion implantation and SOI technology. Applications in telecommunications, transportation, medicine, etc. employ Si-implanted GaAs dual-gate metal semiconductor field effector transistors

(MESFETs), GaAs Hall effect sensors, as well as HgCdTe infrared detectors, light-emitting diodes, and laser devices fabricated by ion implantation. Ion implantation research in metals is also important for improving wear, corrosion, oxidation, and fatigue resistance properties. Reactive ion beam coating has been instrumental in producing thin films of high-T_c superconductors ($Y_1Ba_2Cu_3O_7$), etc. Ion beam enhanced deposition has been employed to synthesize compound films (Si_3N_4;TiN), and the process has been analyzed by a dynamic ion implantation model and a Monte Carlo simulation.

In playing a leading role in engaging such studies and applications in China, the Ion Beam Laboratory has recently focused on research programs as follows:

1. Physical processes of ion beam-solid surface interactions.
2. Ion beam implantation in elemental and compound semiconductors.
3. Surface modification of metal and alloy surfaces by ion beams.
4. Surface modification of ceramic surfaces, composite materials, superconductive materials, and diamonds.
5. Ion beam assisted thin film techniques.
6. Ion beam synthesis of SOI materials and devices.
7. Rapid annealing, laser irradiation of semiconductors.
8. Research and application of surface analysis by ion beams.
9. Physics and application of ion beam sputtering.

A representative list of recent research titles of the Ion Beam Laboratory is given in Appendix C.

As one of China's first open laboratories of the Academia Sinica, IBL accepts foreign visitors as well as Chinese scientists to participate in research within the areas described here, subject to the approval of the program committee of the laboratory. Such arrangements usually last 1 to 2 years and typically involve two to four researchers. At least part of the work should be carried out at the Ion Beam Laboratory, and there is limited funding available, restricted to expenses for materials, machining, computation, measurements, and analysis. Further information relating to application for participation may be obtained from:

Director, Ion Beam Laboratory
Shanghai Institute of Metallurgy
Academia Sinica
865 Chang Ning Road
Shanghai 200050, China

CLOSING REMARKS

One can hardly touch upon the subject of semiconductor physics in China without mention of Kun Huang. His important role in developing semiconductor research in China is amply reflected in the proceedings of a recent festschrift for him under the title *Lattice Dynamics and Semiconductor Physics* [edited by Jian-Bai Xia et al. (World Scientific, 1990)]. Even a brief perusal of this book clearly reveals the important role of Chinese research in semiconductor science. In addition to many research papers, it contains interesting reminiscences of early days by C.N. Yang and a tribute by Xide Xie to the strong impact of Prof. Huang as the major pioneer of semiconductor physics in China. Madam Prof. Xide Xie will chair the forthcoming 21st International Conference on the Physics of Semiconductors (ICPS-21) to be held in Beijing (10-14 August 1992). This will be a forum of major importance for the presentation of recent research developments in semiconductor physics from China and from the world. The satellite Sixth International Conference on Superlattices, Microstructures, and Microdevices (ICSMM-6) to be chaired by Prof. H.Z. Zheng at Xi'an, China (4-7 August 1992), will also be important to watch for new developments. Information about these conferences may be obtained as follows:

ICPS-21

Prof. Xun Wang
Secretary ICPS-21
Physics Department
Fudan University
Shanghai 200433, China
Fax: 86-21-326-9843

also

Prof. Xide Xie
Chairperson, ICPS-21
Fudan University
Shanghai 200433, China
Telex: 33317 HUAFU CN
Fax: 86-21-326-9843

ICSMM-6

Prof. D.S. Jiang
Secretary ICSMM-6
Institute of Semiconductors, CAS
P.O. Box 912
Beijing 100083, China
Fax: 86-1-256-2389

also

Prof. H.Z. Zheng
P.O. Box 912
Institute of Semiconductors, CAS
Beijing, China
Fax: 86-1-256-2389
Tel: 86-1-255-8131

There are several other interesting related satellites of the Beijing semiconductor conference to be held in Japan and Hong Kong in August 1992:

5th International Conference on High Pressure in Semiconductor Physics (V-HPSP), 18-20 August 1992, Kyoto, Japan

Chairman: Prof. S. Minomura
Okayama University of Science
Dept. of Physics
1-1 Ridai-cho
Okayama 700, Japan
Fax: 81-862-55-7700
Tel: 81-862-52-3161

International Conference on the Application of High Magnetic Fields in Semiconductor Physics, 3-7 August 1992, Chiba, Japan

Chairman: Prof. N. Miura
Institute of Solid State Physics
University of Tokyo
Roppongi, Minato-ku
Tokyo 106, Japan
Fax: 81-3-3478-5471
Tel: 81-3-3478-681

5th International Conference on Shallow Impurities in Semiconductors: "Physics and Control of Impurities," 5-8 August 1992, Kobe, Japan

Chairman: Prof. T. Nishino
Secretary: Prof. H. Nakayama
Dept. of Electrical Engineering
Kobe University
Rokkoudai 1-1, Nada-ku
Kobe 657, Japan
Fax: 81-78-861-7679
Tel: 81-78-881-1212 x5088
Bitnet: E00137@jpnac.bitnet

9th International Conference on Hyperfine Interactions (HFI-IX), 17-21 August 1992, Osaka, Japan

Secretary: Dr. Y. Nojiri and
Dr. H. Akai
Dept. of Physics
Faculty of Science
Osaka University
Toyonaka, Osaka 560, Japan
Fax: 81-6-845-0371
Tel: 81-6-843-2497
E-mail: nojiri@jpnoskfm.bitnet

1st Hong Kong Workshop on Current Topics in Physics: Semiconductor Physcs, 3-7 August 1992, Hong Kong

Chairman: Dr. Ping-Wah Chan
Dept. of Applied Physics
Hong Kong Polytechnic
Kowloon, Hong Kong
Fax: 852-333-7629
Phone: 852-766-5694

It should be an interesting summer for semiconductor physics in and around China.

Norman J.M. Horing received a Ph.D. in physics from Harvard University in 1964. From 1960-62 and 1962-65 he was a staff physicist at the Massachusetts Institute of Technology Lincoln Laboratory and National Magnet Laboratory, respectively. During 1965-66 he was a staff physicist at the U.S. Naval Research Laboratory. Prof. Horing joined the faculty of the Stevens Institute of Technology in 1966, and has been in his present position as Professor of Physics since 1975. He has been the director of the institute's Academic Support Center since 1987. Prof. Horing's research interests are in quantum many-particle theory, thermodynamic Green's function methods, high magnetic field phenomena, applications to solid state and semiconductor physics and surface physics, theory of surface interactions and surface response properties and collective modes in quantizing magnetic field, low-dimensional systems, superlattices, nonlinear quantum transport, theory, magnetotransport, and hot electron and hot phonon transport in semiconductor microstructure devices. He is a member of the American Physical Society, the New York Academy of Sciences, the Society of the Sigma Xi, and Phi Beta Kappa.

Appendix A

TITLES OF RECENT NATIONAL LABORATORY FOR SUPERLATTICES AND MICROSTRUCTURES RESEARCH PAPERS

Microscopic Theory of Optic-Phonon Raman Scattering in Quantum Well System, by Kun Huang et al.

Huang's Dipole Lattice Model as Applied to Optical Phonon Modes in 2D and 1D Quantum Systems, by Bangfen Zhu

Raman Scattering in a Superlattice Under an Electric Field, by Hui Tang et al.

Γ-X Mixing Effect in GaAs/AlAs Superlattices and Heterojunctions, by Jian-Bai Xia

Pseudopotential Approach to Long-Period Semiconductor Superlattices, by Jian-Bai Xia

Electronic Structures and Optical Properties of Short-Period GaAs/AlAs Superlattices, by Jian-Bai Xia et al.

Semiclassical and Envelope-Function Treatment of Magnetic Levels in Superlattices Under an In-Plane Magnetic Field, by Jian-Bai Xia et al.

Temperature Dependence of the Cyclotron Resonance Linewidth in a GaAs-AlGaAs Heterostructure, by Xiaoguang Wu et al.

Subband Structure of GaAs/AlGaAs Superlattices Under Crossed Electric and Magnetic Fields, by Wei-Jun Fan et al.

Nonresonant Magneto-Tunneling in Asymmetric GaAs/AlAs Double Barrier Structures, by Houzhi Zheng et al.

Influences of a Parallel Magnetic Field on Localization of Disordered Two-Dimensional Electrons in GaAs/$Al_xGa_{1-x}As$ Heterostructures, by Houzhi Zheng et al.

Characteristics of Nonresonant Magneto-Tunneling Observed in Asymmetric GaAs/AlAs Double-Barrier Structures, by Fuhua Yang et al.

The Physical Origin of Negative Magneto-Resistances Observed in GaAs/$Al_xGa_{1-x}As$ Heterostructures in the Presence of a Parallel Magnetic Field, by Haiping Zhou et al.

Studies on Tunneling Characteristics of Asymmetric GaAs/AlAs Double-Barrier Structures, by Houzhi Zheng et al.

New Features of Resonant Tunneling in Asymmetric GaAs/AlAs Double-Barrier Structures, by Houzhi Zheng et al.

Interaction Effects and Its Influence on Magnetoresistance in Two-Dimensional Hole Systems, by Houzhi Zheng

Progress of Semiconductor Superlattice Science in China, by Houzhi Zheng

Photoluminescence of Strained GaInAs/AlGaAs Quantum Well Structures, by Xinghua Wang et al.

Transport Properties of GaAs/AlGaAs Quantum Wells, by Xinghua Wang et al.

Measurements of Hot Electron Magnetophonon Resonance in GaAs/$Al_xGa_{1-x}As$ Heterostructures, by Wenchao Cheng et al.

Investigation of the Electronic Structures of $(GaAs)_n(AlAs)_n$ Short Period Superlattices by Photoluminescence Spectroscopy Under Hydrostatic Pressure, by Guohua Li et al.

Photoluminescence Studies of GaAs/AlAs Short Period Superlattices Under Hydrostatic Pressure, by Guohua Li et al.

Micro-Raman and Photoluminescence Studies of Embedded GaAs on Si by Molecular Beam Epitaxy, by Guohua Li et al.

Raman Scattering of $GaAs_{1-x}P_x$ Mixed Crystals Under Hydrostatic Pressure, by Guohua Li et al.

Long-Wavelength Optical Phonon Spectra of $Ge_{1-x}Al_xP$ Mixed Crystals, by Zhaoping Wang et al.

Longitudinal Optical Phonon Modes in GaAs/$Al_xGa_{1-x}As$ Superlattices, by Zhaoping Wang et al.

Raman Scattering Studies of LO Phonons in GaAs/$Al_{0.33}Ga_{0.67}As$ Superlattices, by Z.P. Wang et al.

Comparative Study of Photoluminescence of $In_{0.15}Ga_{0.85}As$/GaAs and GaAs/$Al_{0.3}Ga_{0.7}As$ Quantum Wells Under Hydrostatic Pressure, by Li Guhua Zheng et al.

Fermi Edge Singularity in the Luminescence of Modulation-Doped $Ga_{0.47}In_{0.53}As/Al_{0.48}In_{0.52}As$ Single Heterojunctions, by Yong-Hang Zhang et al.

Appendix B

TITLES OF RECENT SURFACE PHYSICS LABORATORY RESEARCH PAPERS

Structural and Vibrational Properties of $(Si)_4/(Ge)_4$ Superlattices, by Jian Zi et al.

Modification of Stillinger-Weber Potentials for Si and Ge, by Jian Zi et al.

Theoretical Study of Structure and Growth of Strained Si/Ge Superlattices, by Jian Zi et al.

RHEED Intensity Oscillation of MBE Grown Ge/Si Ultrathin Multilayered Structures, by Xun Wang et al.

The Determination of the Momentum Matrix Elements Involved in Calculating the Dielectric Constants of Superlattices Using the Tight-Binding Method, by Zhizhong Xu

Substrate-Induced Phonon Frequency Shifts of $(Si)_4/(Ge)_4$ Superlattices, by Jian Zi et al.

Formation of In/GaP (111) Interface Studied by Energy Loss Spectroscopy, X-ray Photoelectron Spectroscopy and Ultraviolet Photoelectron Spectroscopy, by M.R. Yu et al.

Surface Adsorption Properties of GaP (111) Studied by XPS, UPS and HREELS, by H.Y. Xiao et al.

Inverse Photoemission Studies of the Si(100) 2X1 Surface, by Daoxuan Dai et al.

Surface Properties of $Al_{0.7}Ga_{0.3}As$ (100) Studied by XPS and ARUPS, by G.S. Dong et al.

The Electronic Structure of $(NH_4)_2S_x$ Treated GaAs (100) Surface Studied by UPS and XPS, by X.F. Jin et al.

Inverse Photoemission Spectra With High Resolution and High Efficiency, by Daoxuan Dai et al.

Theoretical Prediction of Melting Temperature for Silicon, by Jian Zi et al.

Lattice Dynamics of Strained Si/Ge Superlattices, by Jian Zi et al.

Germanium-Silicon Strained-Layer Superlattices, by Xun Wang

Progress of Semiconductor Physics in China--A Tribute to the Initiator: Prof. Kun Huang, by X.D. Xie

Growth and Characterization of Ge/Si and Ge_xSi_{1-x}/Si Superlattices, by X. Wang, et al.

Investigation of Surface Reconstruction During MBE Growth of Gs/Si(111) and Si/Ge(111) Heterojunctions, by Xun Wang et al.

The Bonding Characterization of Alkali Metal on Si Surface, by X.D. Xie

Synchrotron Radiation Studies of Semiconductor Surfaces and Interfaces, by Xide Xie

Physics and Chemistry of III-V Compound Semiconductor Polar Surfaces, by X. Wang

Chemisorption and Bonding Characterization of Metal on Semiconductor Surface, by L. Ye

Electronic and Optical Properties of Yttria, by W.Y. Ching and Yong-nian Xu

Electronic Structure and Optical Properties of LiB_3O_5, by Yong-nian Xu and W.Y. Ching

Orthogonalized Linear Combinations of Atomic Orbitals Method, IV. Inclusion of Relativistic Corrections, by Xue-fu Zhong et al.

Optical Properties of Vanadium Pentoxide Determined from Ellipsometry and Band Structure Calculations, by J.C. Parker et al.

Electronic Structures of FeB, Fe_2B and Fe_3B Compounds Studied Using First Principles Spin-Polarized Calculations, by W.Y. Ching et al.

Electronic Structure and Possible Mechanism of Potassium Induced Promotion of Oxidation of Si (001) 2X1, by L. Yi et al.

Vanadium Substituted 2212 and 2223 Superconducting Ceramics, by P.C.W. Fung et al.

Surface Donors Induced by Hydrogen and Cesium Absorbed on InP(110) Surfaces, by X.Y. Hou et al.

Structural Chemisorption of Co onto Si (111) 7x7, by G. Rossi et al.

Electronic Structures of Ga- and Zn-Substituted $YBa_2Cu_3O_7$, by Yong-nian Xu et al.

Self-Consistent Band Structures and Optical Calculations in Cubic Ferroelectric Perovskites, by Yong-nian Xu et al.

Appendix C

TITLES OF RECENT ION BEAM LABORATORY RESEARCH PAPERS

Ion Implantation in China, by Shichang Zou & Xianghuai Liu

Electrical Property Analysis of Er^+ Implanted Layer in Si, by Peida Wang & Huiling Sun

A Study of the Mechanism for the Influence of High Density Defect Movement on the Leakage Current of a PN Junction, by Tonghe Zhang et al.

Double-Crystal Diffraction Investigation of High Energy B^+ Implantation in Si, by Anmin Guan et al.

Damage Annealing Behavior in Diatomic Phosphorus Ion Implanted Silicon, by Genqing Yang et al.

Auger Electron and IR Spectroscopic Studies of SOI Structure Formed by Oxygen and Nitrogen Implantation, by Yuehui Yu et al.

Ti Silicide Formation on Thin-Film Silicon on Insulator, by Chenglu Lin et al.

Formation of Crystalline α-Si_3N_4 Layer by Multiple Nitrogen Implantation at High Temperature, by Xianghuai Liu et al.

High Carrier Concentration in InP by Si^+ and P^+ Dual Implantations, by Honglie Shen et al.

A Study of Ion Beam Modification of CoMnNiO Amorphous Films, by Hui Tan et al.

XPS, ^{57}Fe Mossbauer Spectra and Electrical Conductivity Studies on ^{57}Fe-Implanted Polycrystalline Alumina, by Goumei Wang et al.

Investigation on Ion Beam Induced Damage Accumulation Mechanism of Organic Resists, by X.L. Xu et al.

Preparation of High J_c $YBa_2Cu_3O_{7-x}$ Superconducting Thin Films by Ion Beam Sputtering Deposition, by Congxing Ren et al.

Effects of Fluorine Ion Implantation on Superconducting Properties of $YBa_2Cu_3O_{7-x}$ Films, by Yijie Li et al.

Effects of Ion Energy on Microstructure and Properties of IAD Metal Films, by Xianzheng Pan et al.

Formation of Transition Metal Carbide Thin Films by Dual Ion Beam Deposition at Room Temperature, by Min Zhang et al.

Synthesis of Tantalum Carbide Thin Films by Ion Beam Enhanced Deposition, by Min Zhang et al.

Properties and Structure of Silicon Nitride Films Synthesized by Ion Beam Enhanced Deposition, by Xianghuai Liu et al.

Synthesis of Silicon Nitride Films by Ion Beam Enhanced Deposition and Their Protective Properties Against Oxidation, by Shigeji Taniguchi et al.

A Simulation of Ion Beam Enhanced Deposition of Boron Nitride and Silicon Nitride Films, by Binyao Jiang et al.

Synthesis of Titanium Nitride Films by Ion Beam Enhanced Deposition, by Xi Wang et al.

Formation of Titanium Nitride Films by Xe^+ Ion Beam Enhanced Deposition in a N_2 Gas Environment, by Xi Wang et al.

A Preliminary Study on Improving Cutting Tools by Ion Beam Enhanced Deposition, by Zhongchen Zhang et al.

ELECTROTECHNICAL LABORATORY CENTENNIAL HIGHLIGHTS THE FUTURE OF SCIENCE AND TECHNOLOGY

After 100 years of service to the scientific and technological communities, current Electrotechnical Laboratory (ETL) research shows youthful vigor and wise direction to complement a long and distinguished track record. Of particular interest is ETL's effective program for development of compact synchrotron-radiation x-ray sources for x-ray lithography. This program is well connected with semiconductor device development projects as well.

by Victor Rehn

BACKGROUND

Located amid a cluster of public and private research centers in Tsukuba Science City, Ibaraki Prefecture, Japan, the Electrotechnical Laboratory (ETL) is celebrating its centennial. ETL was founded in 1891 by the Ministry (then Bureau) of Electrocommunications. In 1952, ETL became affiliated with the Agency of Industrial Science and Technology (AIST), an element of the Ministry of International Trade and Industry (MITI). A major reorganization in 1970 generated the current name and a new focus on conducting research in broad areas including electrical, electronic, and information-processing technologies for the purpose of ensuring technical innovation. The move to Tsukuba (about an hour from Tokyo) in 1979 provided the campus-like setting and the modern facilities. Some historical highlights are shown in the chronology in Table 1.

SCOPE OF THE RESEARCH PROGRAM

Another major reorganization in 1988 set the current mission as basic research and development (R&D) pursuant to significant technological, economic, and social impact, but which will involve both high risk of failure and a long lead time before impact. Currently, this mission is being pursued by about 545 researchers and 678 support persons on an annual budget of about $77M. By its own count, ETL is Japan's largest national research institute. See Figure 1 for budgetary allocations. One of the events of its centennial celebration was an elaborate, well-organized, and well-attended 2-day open house. Four major areas of current R&D activities were highlighted in self-guided laboratory tours:

- Electronics
- Standards and Measurement Technology
- Energy Technology
- Information Technology

As shown in Table 2, the organization supports these four research areas without specific organizational identification.

A tabulation of ETL research themes is shown in Table 3. Here the joint programs with the private sector and with other governmental agencies are shown specifically, albeit without associated budget figures. The tremendous breadth of the ETL research program is evident in Table 3: medical and welfare equipment technology, human frontier science program, technologies for global environment, and international joint research projects are notable examples.

ELECTRONICS RESEARCH

Self-guiding tours of 12 laboratory exhibits in each research area began in an eighth floor exhibit room and continued sequentially to laboratories throughout the campus-like ETL complex. Some highlights of fundamental scientific research in the electronics area were:

- A high sensitivity Hall device of strained, pseudomorphic $In_{0.8}Ga_{0.2}As/In_{0.52}Al_{0.48}As/InP$ (semi-insulating), which demonstrated electron mobility greater than 10^6 cm^2/V-s at 4 K.

Table 1. Chronology of the Electrotechnical Laboratory (ETL)

Year	Event
1876	Insulator Testing Lab, forerunner of ETL.
1891	ETL was established in the Ministry of Communication.
1896	ETL started research on wireless telegraphy.
1936	ETL started research on extra-high voltage power transmission, establishing the foundation for extra-high voltage power transmission in Japan.
1941	The 50th anniversary.
1948	Became part of the Agency of Industrial Science and Technology. The part concerned with communication was transferred to the Nippon Telegraph and Telephone Public Corp. to establish the Electrical Communication Lab.
1958	Nuclear fusion research began.
1959	Development of the first transistor computer with stored program (Mark-IV).
1963	The part concerned with electrical appliances was separated to establish the Japan Electrical Testing Lab.
1964	Elucidation of "phenomenon of resistance minimum" (Kondo effect).
1965	The part concerned with the inspection and testing of electrical meters was separated to establish the Japan Electric Meters Inspection Corp. All effort at ETL to be concentrated on research work.
1966	Large-scale project began.
1970	Reorganized to strengthen activities in the field of electronics.
1978	Moonlight project began.
1979	Moved from Tokyo to Tsukuba Science City to lay the foundation for progress as an updated research organization adapted to the age of internationalization.
1980	Development of the pattern information processing system.
1981	A magnetohydrodynamic power generator, Mark VII, succeeded continuous operation of more than 200 hours for electric power output of 100 kW.
1981	Key Technology for Future Industries project began.
1988	Reorganized.
1989	World's first Josephson computer, "ETL-JC1," was developed.
1991	Centennial celebration.

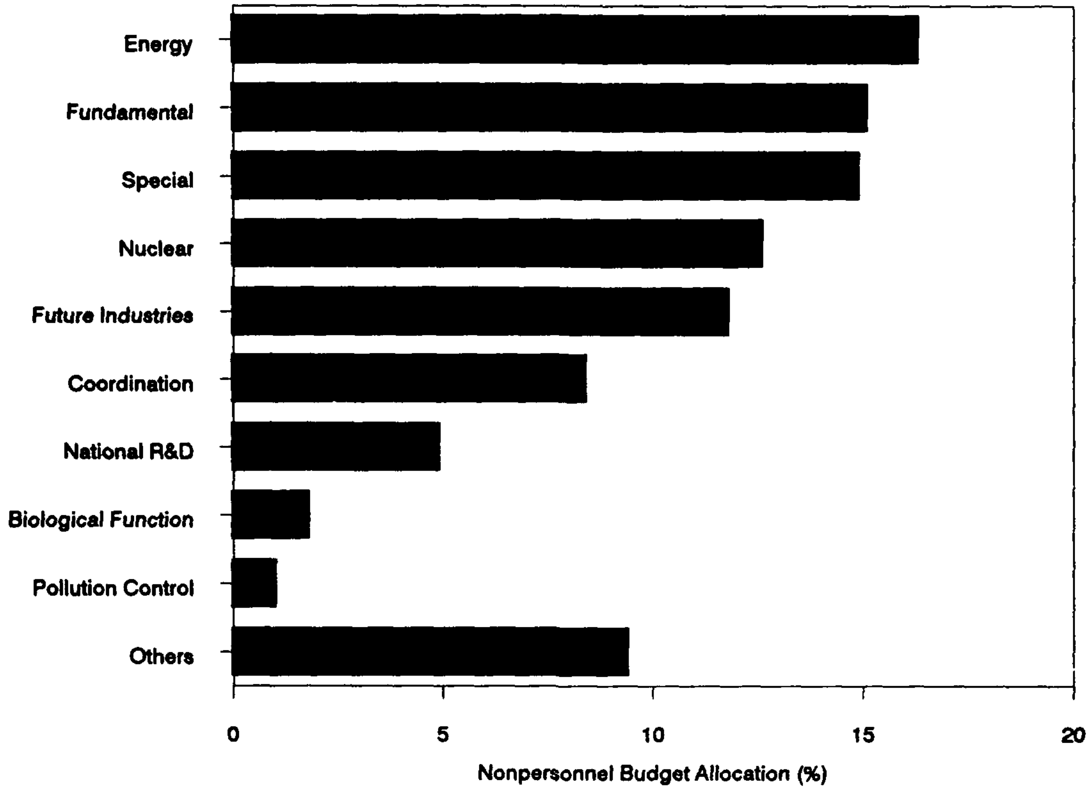

Figure 1. ETL budget distribution. *Personnel expenses, totaling 51% of the budget, are subtracted before the above percentages are calculated.*

- A study of the current-voltage (I-V) behavior of a triple-barrier resonant tunnel diode showing a very sharp negative resistance region.
- A study of a chirped superlattice of GaAs and $Al_{0.1}Ga_{0.9}As$.
- A reflection high-energy electron diffraction (RHEED) study of the melting-point lowering in very thin films of Al on GaAs.
- A RHEED study of atomic layer-by-atomic layer desorption (i.e., evaporation) of GaAs.
- A study of the alteration of the band-structure type (from indirect gap to direct gap) in strained-layer Ge-Si superlattice grown by phase-locked (RHEED-controlled) epitaxy.
- A study of Fe-Au magnetic superlattice by RHEED and SMOKE (surface magneto-optical Kerr effect).
- Research progress in Co/Cu metallic superlattices on (100) and (111) substrates.
- Langmuir-Blodgett film research on organic superconductors.
- Scanning tunnelling microscopic (STM) images of hydrogen atoms on the surface of hydrogenated a-Si.

In the area of electronic device research and development, there were many displays. Some examples were:

- A study of superconducting monostatic (MONOS) memory, billed as the next generation electrically erasable/programmable read-only memory (EEPROM).
- A 128-unit linear infrared (IR) detector array, self-scan type, of InSb.
- An f/2 thermal video camera utilizing 128 x 128 InSb detector array integrated with Si metal oxide semiconductor field effect transistors (MOSFETs).
- A strained-layer, pseudomorphic high electron mobility transistor (HEMT) utilizing $In_{0.8}Ga_{0.2}As/In_{0.52}Al_{0.48}As/InP$.
- A study of operating characteristics of a GaAs insulated-base transistor operating at 77 K.
- A study of the operation of coupled GaAs p-FET and n-FET in semiconductor-insulator-semiconductor FET (SISFET) structure.

Table 2. Organization of Electrotechnical Laboratory

Director General, Hiroshi KASHIWAGI

Deputy Director General | **Advisory Fellow**
Chief Senior Researcher | **Research Planning Office**

International Affairs Office
Mikio YAMASHITA

Technical Information Office
Hisao NAKAMURA

Physical Sciences Div.
Koji KAJIMURA
Fundamental Physics Sect.
Exotic Mat'ls Physics Sect.
Electron Physics Sect.
Applied Physics Sect.

Materials Science Div.
Kazunobu TANAKA
Mat'l Fundamentals Sect.
Nonequilib. Mat'ls Sect.
Quantum Mat'ls Sect.
Superconductive Mat'ls Sect.
Optoelectronic Mat'ls Sect.

Electron Devices Div.
Masatoshi ONO
Device Functions Sect.
Device Synthesis Sect.
Process Fundamentals Sect.
Micro-Beam Sect.
Microstructure Electr. Sect.
Superconductive Electr. Sect.

Optoelectronics Div.
Jun'ichi SHIMADA
Laser Sect.
Photonprocess Sect.
Optical Information Sect.
Light and Radio Waves Sect.

Energy Technology Div.
Toshitada ONISHI
Environmental Energy Sect.
High Temp. Energy Sect.
Supercond. Applications Sect.
Energy & Info. Sci. Sect.

Metrology Fundamentals Div.
Hajime MIURA
Advanced Metrology Sect.
Electronic Metrology Sect.
Acoustics Sect.

Supermolecular Science Div.
Gen MATSUMOTO
Molecular Physics Sect.
Molecular Electronics Sect.
Molecular & Cellular Neurosci. Sect.

Frontier Technology Div.
Yoichi KIMURA
Space Technology Sect.
High Density Energy Sect.
Superconductor Technol. Sect.
Surface Engineering Sect.

Energy Fundamentals Div.
Kiwamu SUGISAKI
Fund. Energy Technol. Sect.
Energy Materials Sect.
Plasma Sect.

Information Science Div.
Koichiro TAMURA
Mathematical Informatics Sect.
Neuroscience Sect.
Cognitive Science Sect.

Quantum Radiation Div.
Takio Tomimasu
Optical Radiation Sect.
Radiation Metrology Sect.
High Energy Radiation Sect.
Appl. Radiation Physics Sect.

Computer Science Div.
Toshitsugu YUBA
Computer Models Sect.
Computer Architecture Sect.
Computer Language Sect.
Information Base Sect.
Distributed Systems Sect.

Machine Understanding Div.
Nobuyuki OTSU
Machine Interface Sect.
Natural Language Sect.
Speech Processing Sect.
Image Understanding Sect.

Intelligent Systems Div.
Kunikatsu TAKASE
Computer Vision Sect.
Intelligent Machine Behavior Sect.
Autonomous Systems Sect.
Interactive Interface Systems Sect.

Life Electronics Research Center (Osaka)
Totoi NANJO
Bioelectronic Interface Sect.
Environmental Sensing Sect.

General Affairs Div.
Toshimi TATESHITA

Table 3. Main R&D Themes at the Electrotechnical Laboratory, 1991

Special Research Projects
1. Advanced Technologies for Measuring Light Wave, Magnetic, and Ultrasonic Fields
2. Quantum Effects-Based Electric Standards and Basic Technologies for Electromagnetic and Acoustic Standards
3. Integrated Information Processing in Biological Systems
4. Reaction Process-Controlled Material Synthesis
5. Production of New Surface Materials Using Energetic Particles and Laser Photons
6. Optoelectronic Computer
7. Superconductor Electronics
8. Optoelectronic Materials
9. New Applications of STM
10. New Functional Structures of Electron Devices
11. Electronic Properties of Superstructure Materials
12. Electronic Functional Supermolecules
13. Basic Technology for X-ray Lasers
14. Advanced Technologies for Large-Scale Satellite
15. Computer Vision Technology
16. Conversation System in Natural Language
17. Flexible Information System Architecture
18. Cooperative Autonomous Systems for Real Environments
19. Integrated Processing of Multimorphic Information
20. Microscopic Reaction Dynamics in Various CVD Systems
21. Next Generation Manufacturing Systems

Research Project on Peaceful Utilization Technology of Nuclear Energy
1. Nuclear Fusion Reaction
2. Generation and Application of High-Quality Ionizing Radiations
3. Active Environment-Understanding Robots for Use in Nuclear Reactor Facilities
4. Laser Technology Using Nonlinear Processes
5. Radiation-Resistant Semiconductors
6. Evaluation of Applicability of Information Acquisition and Processing Systems to Autonomous Power Plants
7. Basic Study on Free Electron Laser Oscillation
8. High-Field Pulsed Superconducting Magnet
9. Evaluation of Radiation Effects and Their Standardization
10. KrF Excimer Laser Driver for Inertial Confinement Nuclear Fusion
11. Development of High-Performance Radiation Detectors and Their Applications

Research Project on Pollution Control Technology
1. Structure of Lower Trophic Ecosystem in an Eutrophicated Bay
2. Psychological and Physiological Measurements of Fluctuating Offensive Odors

Basic Technologies for Future Industries
1. Photoactive Materials
2. Bioelectronic Devices
3. Superconducting Materials and Electron Devices
4. Molecular Assemblies for Functional Protein System
5. Nonlinear Optoelectronic Materials
6. New Software Architecture
7. Development of Quantized Functional Devices

National R&D Program (Larger Scale Project)
1. Interoperable Database System
2. Advanced Material Processing and Machining System
3. Human Senses Measuring Technologies and Their Applications

R&D on New Energy Technology (Sunshine Project)
1. Solar Photovoltaic Power Generation System
2. Analysis and Evaluation for Practical Use of Amorphous Solar Cells
3. Solar Thermal Energy System
4. Analysis and Evaluation for Development of Peripheral Technology for New Energy
5. Analysis and Evaluation for Practical Use of New-Type Solar Cells
6. Ocean Thermal Energy Conversion System
7. Assessment of the Development of New Energy Technology

R&D on Energy Conservation Technology (Moonlight Project)
1. Advanced Battery Electric Power Storage System
2. Fuel Cell Power Generation Technology
3. Superconducting Technology for Electric Power Apparatuses
4. Sodium Thermoelectric Conversion Technology
5. Combined Cycle Generation Using Binary Mixture Working Fluid
6. Technological Forecasting and Assessment on Energy Conservation

Medical and Welfare Equipment Technology
1. Three-Dimensional Imaging System for Medical Diagnosis

Joint Government-Private Sector Research
1. Positron Microscope Technology
2. Technology for High Speed Josephson Integrated Systems

Human Frontier Science Program
1. Sensory, Cognitive, and Motor Functions
2. Memory and Learning Functions
3. Biological Energy Conversion
4. Molecular Recognition and Responsive Function

Specific International Joint Research Projects
1. Precision Evaluation of New Superconductors and Development of Precision Measurement Devices

Promotion of Research Cooperation Project
1. Development of Machine Translation System for Southeast Asian Languages

Technologies for Global Environment
1. Analysis and Evaluation of Technologies for Reducing Anthropogenic CO_2 Emissions
2. Coral Reefs as Sinks of Atmospheric CO_2

R&D Based on Subsidy of Science and Technology Agency
1. High Performance Superconducting Electronic Devices, and 12 other themes

Fundamental Research
1. Response Theory of Solid State Electronic Systems, and 77 other themes

- Electron-beam lithography with 20 nm line widths.

- A study of GaAs field-emitting arrays for vacuum electronics fabricated by the focussed ion-beam technique.

- A study of buried heterostructure, $Al_{0.1}Ga_{0.9}As/Al_{0.3}Ga_{0.7}As$, surface-emitting laser.

- Amorphous-Si photocells with 12% efficiency, made by plasma deposition. The defect density was minimized via spectroscopic plasma control to maximize the SiH_3 species considered to give superior deposition.

- A metal-film-edge field emitter array with a self-aligned gate (Ref 1).

- Silicon vacuum photocathode arrays fabricated using SiN photoresist and SiO insulators (Ref 2).

- An ultrafast sampling system (rise time of 0.4 to 0.8 ps) utilizing $LiTaO_3$/GaAs.

As part of the research in ultrafast sampling systems, an ultra-short-pulse laser system was developed. Using the colliding-pulse mode-lock concept, pulses less than 40 fs ($= 4 \times 10^{-14}$ s) (full width at half maximum intensity) have been produced. Using a sampling head consisting of a $LiTaO_3$ electro-optic crystal on GaAs substrate, the rise time of the sampling head was measured to be <1 ps ($= 1 \times 10^{-12}$ s). The measurement used a pump-probe arrangement of the laser beams. Measurements of the rise time versus propagation distance between pump and probe pulses were shown.

Applications of electronic research methods to living systems were shown in two exhibits:

- A computerized magnetoencephalographic recording system that records brain responses from 16,000 locations simultaneously.

- A live-squid tank supporting studies of the giant axon in the super-simple nervous system of the squid.

SYNCHROTRON-RADIATION SOURCE DEVELOPMENT

In a recent review of synchrotron-radiation (SR) sources worldwide, nine are listed as operational sources dedicated for x-ray lithography (Ref 3). Of these, eight are in Japan and one is at IBM, Fishkill, NY. Four of the Japanese sources are in Tsukuba Science City, two of which are at ETL. The 9 SR sources dedicated for x-ray lithography are in addition to 29 other SR sources in 12 countries, operational or under construction, that are utilized for research in many fields of science. Of the 29 research sources, 5 are in Japan.

The Photon Factory (PF) is Japan's largest laboratory for SR research, located in Tsukuba across town from ETL. The PF operates a large, 2.5-GeV storage ring as a national user facility, with 20 beam lines and 57 experiment stations covering the spectral range from infrared to hard x ray. In addition, the PF is utilizing the 6-GeV accelerator ring of the huge 30-GeV high-energy-physics electron storage ring, Tristan, where three beam lines with six experiment stations are available for users conducting experiments with very high energy x rays.

Within the research area of standards and measurement research, ETL has placed emphasis for the past dozen years on the development and utilization of SR sources for laboratory use. By contrast with PF, the storage rings at ETL are run for use by internal research staff (and their collaborators) only. A high-current 500-MeV electron linear accelerator, TELL, was placed in operation in 1980 (Ref 4). Currently, this source of high-energy electrons is utilized for injecting electrons into four storage rings, all of which are used for SR research. The largest and oldest, TERAS, is an 800-MeV ring completed in 1981. TERAS has been used for a variety of research on atomic, molecular, and solid state physics; optical devices; the formation of stratospheric particles; and lithographic technology research for ULSI (ultra-large-scale integration). It is instrumented with five beam lines and eight experimental stations, including a recently developed undulating-electron-beam station that produces uniform large-area exposures for lithography. Another recent development is the arbitrary-polarization undulator, which produces SR with circular, elliptical, or linear polarization as needed by the experimenter (Ref 5). A visible-light free-electron laser (FEL) experiment uses a 1.5-m-long undulator. Both the spectral and temporal characteristics of visible FEL radiation have been reported recently (Ref 6). For angiography research and extended x-ray absorption fine structure (EXAFS) experiments, a new, very high field (10 T) superconducting-magnet, three-pole x-ray wiggler is being developed. Experiments on lengthening the stored-beam lifetime of storage rings have shown that vacuum-chamber outgassing using SR can significantly improve the lifetime. Beam lifetime is important in applications of x-ray lithography to manufacturing because it impacts the financial feasibility of the process.

A collaboration with Sumitomo Electronic Industries (SEI) (a competitor of Sumitomo Heavy Industries in this field) was begun in 1985 for development of compact SR sources for laboratory use (x-ray lithography). The first of a series, NIJI-I, was installed at ETL in 1986 and replaced in 1989 by NIJI-II. ("Niji" is the Japanese word

for "rainbow," an appropriate name for a broad-band SR source.) NIJI-II is a 600-MeV storage ring using four conventional bending magnets. It has two long, straight sections in which a 1.36-m-long undulator for chemical vapor deposition (CVD) research and a 1.30-m-long undulator with crossed and retarded magnetic fields have been installed. Recent studies of the characteristics of this uniquely controllable undulator have been presented, showing the comparison of theoretical and experimental absolute brightness in the 350- to 700-nm wavelength range (Ref 7).

NIJI-III is the latest result of the collaboration with SEI. This is a 620 MeV storage ring that utilizes 4-T superconducting bending magnets in a compact design. Development of NIJI-III was sponsored by the Prime Minister's Science and Technology Agency through its Research and Development Corporation of Japan (JRDC). NIJI-III is a prototype development, being tested by ETL with the plan to return the ring to SEI for subsequent use in ULSI research and perhaps to lead to commercial production of compact storage rings. Currently, the commercial price of a NIJI-III type storage ring without beam lines is estimated to be about ¥2B ($15M), a very competitive price!

The newest ETL rainbow is NIJI-IV, a 500-MeV conventional-magnet storage ring with two straight sections, over 7 m in length. This ring was built by Kawasaki Heavy Industries with very low emittance (design: 5×10^{-8} m-rad), as needed for ultraviolet and soft x-ray free-electron lasers. The low emittance is obtained using a magnetic lattice of the "triple-bend acromat" type, the same type used to achieve extremely low emittance in the new Advanced Light Source storage ring in Berkeley. NIJI-IV will be operated in ...gle-bunch mode with stored current at least 20 mA for driving the free-electron laser.

Another off-site storage ring is SORTEC, a 1-GeV storage ring built by the SORTEC Corporation with ETL collaboration in 1989. The SORTEC Corporation is a joint venture established in 1986 by the Japan Key Technology Center and 13 private industries. The SORTEC ring is a dedicated x-ray lithography facility, currently operating for users 8 hours per day, 4 days a week, with an average beam current of 185 mA, a 10-hour lifetime, and operation optimized for soft x-ray radiation of wavelength in the range of 0.7 to 1.3 nm. Four beam lines are currently available. It is planned that the beam current will be increased in mid-1992, thereby shortening exposure times and increasing the lithography wafers per day output possible.

SR RESEARCH

A variety of ETL research projects utilize SR in one way or another. The SR facilities are operated by a separate group, but the research of many divisions of ETL integrates SR techniques into its experimental program. A couple of examples of such projects are as follows:

- One research group working mainly on TERAS has measured the quantum efficiencies of photodiode detectors in the vacuum ultraviolet (Ref 8). In this research, optical, transmission, and reflectance were measured, along with photocurrent, and a model of the detector efficiency was compared with the measured quantum efficiency for both Si and $GaAs_{0.6}P_{0.4}$ photodiodes.

- A new method has been developed for utilization of SR x rays for determining the crystal structure and orientation of growing epitaxial films in situ in the growth chamber (Ref 9). The automated goniometer is built on a single large flange and has been introduced into a molecular beam epitaxy system used for growing Si-Ge alloy crystals.

Following the University of Tokyo's synchrotron orbital radiation (SOR) facility, ETL was the second laboratory in Japan to build and operate an SR facility for use by its internal research staff. The Institute for Molecular Science at Okazaki built Japan's third internal, integrated SR facility. The cost of operating and maintaining SR facilities has made it difficult for single institutions to support dedicated, internal SR facilities. In comparison, until recently only the National Institute of Standards and Technology (NIST) in the United States has operated its own internal SR facility. Now the University of Louisiana is in the process of establishing its own SR facility. Other SR facilities in the United States and elsewhere are mainly or mostly utilized as national user facilities, available to "any qualified scientist." In this case, the host organization accepts the responsibility for maintaining and operating the facility, but internal scientists must compete on an equal basis with outside scientists for "beam time." The ETL experience makes it clear that there are advantages to the dedicated, "internal-only" SR facility. New compact SR sources developed for ETL and elsewhere may make such SR facilities economically feasible in the future.

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FIRST INTERNATIONAL WORKSHOP ON RECENT ADVANCES IN NONLINEAR OPTICALLY ACTIVE ORGANIC MATERIALS

Highlights of developments in the field of nonlinear optically active organic materials, presented at the Army Research Office Far East cosponsored workshop held on 11-12 October 1991, are summarized.

by Iqbal Ahmad

INTRODUCTION

Nonlinear optical (NLO) materials are characterized by their nonlinear polarization response to a laser beam electric field. The field of nonlinear optics has gradually developed since the discovery of lasers. Earlier work concentrated on inorganic ferroelectric and semiconducting materials, which led to the development of a number of devices such as optical modulators, second harmonic generators, and switches. Some of the devices have been already commercialized. Recently, through the molecular engineering approach of optimizing nonlinear optical properties, a number of new organic materials possessing much larger nonlinear optical efficiencies have been reported. They have attracted much attention as possible key materials for information processing for the 21st century. Consequently, there is worldwide research activity to identify novel NLO organic molecular and polymeric materials as well as use them in optoelectronic devices.

To review the current state of the art and recent advances in this fertile field, a workshop sponsored by the Army Research Office Far East (AROFE) was organized by the Organic Photonic Materials Research Group at the Research Institute of Economy and Industry, Tokyo University of Agriculture and Technology. It was held on 11-12 October 1991 at the Shokuryo Keikan, Kojimachi, Tokyo. The chairman was Dr. Hiroyuki Sasabe of RIKEN. In addition to the attendees from Japan, active researchers from the United States, France, and Korea participated. In the following some of the highlights of the presentations and discussions are summarized. A Proceedings of the workshop will be published in the near future.

MATERIALS FOR SECOND HARMONIC GENERATION

In recent years there has been increasing emphasis on the theoretical and experimental studies of the nature of the highly conjugated π electron states in organic crystals and polymeric materials that are responsible for their exceptionally large, second order nonlinear optical susceptibilities $X^{(2)}$. Specifically in view of their application in second harmonic generation (SHG) and electro-optic light modulation, poled polymers (Ref 1) have received much attention. The large $X^{(2)}$ values of the poled polymers depend on both the poling electric field and the second order hyperpolarizability, β, of the dopant molecules or the pendant molecular units (Ref 2). The β values arise principally from the π electron conjugated systems substituted by electron donor and acceptor groups. The magnitude of these values depends on the electron affinity of the acceptor and ionization potential of the donor groups, as well as on the length and nature of the π electron conjugated backbone structure. These trends have been examined in the light of general phenomenological models such as the equivalent internal field model and the two level charge transfer model (Ref 3). The most striking advantage of the poled polymers is the primarily pure electronic origin of large β values over the entire frequency range from dc to optical frequencies, unlike the inorganic ferroelectric crystals such as KH_2PO_4 (KDP) and $LiNbO_3$ (LN), where the nonlinear optical response includes acoustic and optical phonon contributions.

Dr. Yoshito Shuto of the NTT Optoelectronic Laboratories, Ibaraki, reported the hyperpolarizabilities β of both the conventional monoazo dye Disperse-Red 1 (DR 1) and some novel diazo dyes determined by the solvatochromic method. Nonlinear optical susceptibilities $X^{(2)}$ of the dye substituted, poled polymethyl methacrylate copolymerized with methacrylate esters of DR 1 and nitro and dicyano-terminated azo dye derivatives and their

relationship with microscopic β values of the dye molecular units were evaluated. Each of the dye molecules studied had a nitro group or a dicyanovinyl group as an electron acceptor and a diethylamino group as an electron donor. Shuto proposed a molecular statistical model to describe the relationship of the bulk $X^{(2)}$ and β values in the presence of a poling electric field, which explained the large $X^{(2)}$ value of 1×10^{-6} esu at 1.06 μm for corona poled polymer doped with dicyanovinyl terminated diazo dye derivatives.

Dr. Joseph Zyss of CNET, France, reported a new molecular and material engineering route based on the compatibility of previously reported beta enhancing features and a strict cancellation of all vector-like observables including the ground state dipole moment (Ref 4). It was shown that the dramatic reduction of rotational spectra such as cancellation of all irreducible components of order lower than J (except for the J=0 totally symmetrical representation) would result from multipolar order 2^J of the molecular or material symmetry group. This consideration supports the relevance of the octupolar (J=3) groups in the context of quadratic linear optics with the trigonal D_{3h} group standing out. The first reported example of a molecule and subsequent crystalline lattice showing significant second harmonic generation efficiency and complying with these symmetry criteria is 1-3-5, triamino 2-4-6, trinitrobenzene (TATB) (Ref 5). In this presentation Zyss also discussed the guanidinium complexes and a few other molecules and suggested that owing to the absence of dipoles and a more rounded shape of these molecules, they would have the advantage over para nitroaniline-like molecules as they were expected to be easily crystallizable, have a more favorable statistical occurrence of noncentrosymmetric crystal lattices, and have an optimized ratio of off-diagonal versus diagonal beta tensor components and subsequent implications for device operation. Zyss also critiqued the traditional two-level quantum model, which relies on ground and excited state dipoles and is thus unable to account for the observed nonlinearities of octupolar systems. He proposed a three-level system instead and discussed various quantum mechanical approaches of the problem. Further details of this work are reported in the Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE) meeting held in San Diego in August 1991.

The molecular arrangement for crystal engineering containing bulky substituents of biphenyls or hindered phenol derivatives for SHG materials is the subject of the studies by Prof. Masaru Matsuoka of the Department of Chemistry, University of Osaka Prefecture, Sakai. He discussed the effects of substituents on SHG efficiency of twisted biphenyls and hindered phenols and reported that in systems with high SHG efficiency, the 3,5 di-t-butyl group played an important role in effective molecular packing of biphenyl and phenyl derivatives.

As a part of the Ministry of International Trade and Industry's (MITI) Frontier Research Program at RIKEN, Saitama, Dr. Tatsuo Wada has studied the poling dynamics of polymers. In his presentation Wada reported experimental results of the optical second harmonic generation and spectroscopic absorption measurements performed to examine the electric field induced polar alignment in polymethyl methacrylate (PMMA) doped with 10% azo dye (DR 1) and polyurethane containing nitrostilbene moiety in the side chain. The dynamics of molecular orientation were monitored during the corona poling process with a parallel wire electrode configuration by measurement of absorption and transient SHG. A decrease in the intensity of the absorption spectrum observed after corona poling was attributed to the alignment of dipolar chromophores in the direction of the poling field. Measurements of in situ poling or depoling showed that covalently attached polymers had longer time constants than molecularly doped polymers.

A general problem of poled polymers is the decay of their nonlinear optical coefficients due to local relaxation processes of polymer side chains (Ref 6) and low orientation order parameters. Prof. Miyata and Dr. Watanabe presented a novel approach that forms SHG active p-nitroaniline (p-NA) crystals spontaneously in polymer matrices even in the absence of an electric field. Thin film from a solution of 10% to 50% p-NA and poly ϵ-caprolactone (PCL) in benzene was formed on a transparent substrate by spin coating. Highly aligned SHG active p-NA crystals, so-called transcrystals, are formed by scratching the spin coated film before it crystallizes. The SHG intensity was found to increase with an increase of p-NA content. At 21.6% p-NA, the SHG intensity was three to four times larger than 2-methyl-4-nitroaniline (MNA). Moreover, its nonlinear optical coefficient is quite stable at room temperature for more than 1 year.

Use of polymeric optical materials for second harmonic generation of diode lasers for optical storage was discussed by Dr. D.M. Burland of IBM Research Division, Almaden Research Center, San Jose, California. This application is important because it is clear that to move into the Gbit/cm^2 storage regime, the effective operating wavelength of the laser system must be shorter than 500 nm. This wavelength can be obtained either by developing a blue diode laser or through frequency doubling of the existing infrared diode lasers. Burland explained that in order to design an optical storage device, it would be desirable to have on the order of 5 to 10 mW of blue light incident on the surface of the optical disc. Making allowances for the losses in the optical system between the light source and the disc,

10 mW appears to be a lower limit on the source power. A typical GaAlAs laser can generate on the order of 100 mW in a single spatial mode at 800 nm. One thus needs a frequency doubling device with at least 10% output conversion efficiency when pumped with 100 mW of input power. Considering a polymer slab waveguide for a frequency doubling device, it can be shown that a value of $X^{(2)}$ of 60 pm/V would be needed (Ref 7). For second harmonic generation a figure of merit $X^{(2)}/n^3$ and the transparency wavelength range are used to select candidate materials. On the basis of the figure of merit, Burland identified poly-p-nitroaniline polymer (PPNA) and organic crystal 2-methyl-4-methoxy-4'-nitrostilbene (MMONS) as possible candidates. However, he stated that no materials were known that satisfy both transparency and figure of merit requirements. So the major problem to be solved for organic materials is the reduction in the absorption at 2 ω. He also showed that no p-substituted benzenes and substituted stilbenes or tolanes, among the poled polymers, have qualified as yet as practical chromophores for frequency doubling. He suggested that the indirect link between wavelength of absorption maximum and β, calculated by assuming the validity of the two-level model, makes it difficult to find chromophores that would simultaneously exhibit efficient frequency doubling without absorption at the second harmonic.

The work reported by Dr. Khanarian of the Hoechst Celanese Research Co., Summit, New Jersey, supports the research of Burland. He reviewed the underlying principles of organic dyes for frequency doubling, their poling in polymers, and the fabrication of waveguides. In the experimental work performed, the technique of quasi-phase matching applied by both periodic poling and bleaching was used. Waveguides in the form of thin (1-10μm) films were fabricated by spin coating and standard lithographic techniques. A pulsed dye laser/H2 cell system tunable near 1.3μm was end fired into the slab waveguide mounted on a rotating stage. Since the fabricated periodicity (6μm) was slightly below the phase matching coherence length (6.2 μm), the slab waveguide was rotated to lengthen the grating until phase matching was observed. From the angular dependence one can deduce that the phase matching had occurred over a distance of 5 mm and the efficiency of the slab doubler was about 0.01 %/W. In the case of periodically bleached samples, the waveguides were more lossy and the wave matching occurred over only a distance of 1 mm. Recently, great strides have been made in frequency doubling in potassium titanyl phosphate (KTP), lithium tantalate, and lithium niobate periodically domain inverted waveguides. Comparing the results with the organic polymer devices, it is clear that great improvements have to be made in polymer doublers in order to become competitive with the inorganic doublers.

The success of nonlinear optical devices depends on the availability of appropriate organic crystals. Prof. Sherwood of the Department of Pure and Applied Chemistry, University of Strathclyde, United Kingdom, described his work on 4-nitro-4'-methylbenzylidene aniline (NMBA), which is composed of linear molecules of high intrinsic second order hyperpolarizability and which pack in the solid state in a noncentrosymmetric and well-aligned form. NMBA crystals, therefore, have excellent modulation properties and high potential for Pockels cells and other equivalent applications. However, to grow them in the form of large single crystals is not easy. Sherwood reported successful preparation of large (5 by 3 by 1 cm^3) single crystal tablets of high perfection by the use of selective seeding techniques starting from long, fine, hairlike crystals developed from an n-hexane solution. The seeding was done in a solution of NMBA in ethyl acetate. The reduced half wave voltages of cut and polished specimens were found to be 2.8, 1.3, and 1.1 kV at 632.8, 514.5, and 488.0 nm, respectively. The thermal variation of the birefringence was also investigated and the temperature variation of the refractive index difference d Δ n/dT was 15.8 x 10^{-5} K.

MATERIALS FOR THIRD HARMONIC GENERATION

In the area of third order nonlinearity, Mr. Y. Suda of Tokyo Ink Manufacturing Co. Ltd., Tsukuba, Ibaraki, discussed his company's work on the metallophthalocyanine derivatives with axial ligands, which are known to have at least one order of magnitude larger $X^{(3)}$ values than those without axial ligands. He reported that the loose aggregation of tetrakis-(alkylthio) phthalocyanine gave $X^{(3)}$ values several times larger than those of co-facially aggregated ones at the same resonant wavelength. This dimeric aggregation at room temperature is derived from the permanent dipole and the liquid crystalline state. Thus, the unsymmetrically substituted phthalocyanines with a lone alkyl chain must be a better candidate for third order nonlinear optics.

Although there has been considerable research activity on the third order nonlinear optical behavior of organic molecules with linear chain structures, there are only a few theoretical or experimental studies on two-dimensional π electron systems. Wada described the molecular design and assembly of macrocyclic conjugated systems such as annulenes with an 18-28 membered ring size and metallophthalocyanine systems and their third order nonlinear optical properties. He reported that the third order optical response of tetradehydromethano annulenes increased with increased size of the macrocyclic conjugated structure. Wada also reported enhancement of third harmonic susceptibility in

vanadyl phthalocyanine (VOPc) vacuum deposited film because of a staggered stacking arrangement induced by thermal treatment.

Prof. P.N. Prasad from the State University of New York (SUNY) at Buffalo reviewed ongoing work in the Photonic Research Laboratory, of which he is the director. He stated that for optimization of molecular and polymeric materials for nonlinear optics, the strategy followed in his laboratory includes optimization at molecular level, optimization at bulk level, experimental studies, and investigation of device processes. One of the many accomplishments reported by him was the use of a modified sol gel process for preparing a new class of inorganic oxide/organic compound composites, which have a combination of superior low loss transmission characteristics of glass and high third order nonlinear coefficient of polymer materials. Such materials produced at SUNY Buffalo include SiO_2 glass/conjugated polymers (poly-p-phenylene vinylene and its derivatives) and V_2O_5/conjugated polymers. He also reported successful fabrication of a number of device applications of these materials.

Dr. F.J. Bartoli from the Naval Research Laboratory discussed the third order nonlinear properties of C^{60} films. The molecular cluster C^{60}, a new stable form of carbon, is also an attractive candidate for nonlinear studies because of its extensively delocalized three-dimensional π electron system. Degenerate four wave mixing measurements were made in the standard counter-propagating pump beam geometry using a passive mode-locked, Q-switched Nd:YAG laser with a 35-ps pulse width. Time resolved studies were conducted by introducing delays in the backward pumped beam. A half wave plate in the probe beam was rotated to determine independently $X^{(3)}_{xxxx}$ and $X^{(3)}_{xyyx}$ tensor components. Similar measurements were made on Pt, Co, Ni, Cu, and Pb tetrakis-(cumulphenoxy) phthalocyanines and all the bis-phthalocyanines. Generally these metallophthalocyanines exhibited a cubic intensity dependence, as expected of a third order nonlinear process. For several phthalocyanines and C^{60} the intensity dependence was significantly greater than cubic. This behavior was suggested to be due to the contribution from higher order $X^{(5)}$ processes, probably associated with a two phonon induced transient grating.

OTHER IMPORTANT DEVELOPMENTS REPORTED

Prof. A.J. Heeger of the University of California at Santa Barbara reported the light emission from diodes fabricated with poly[2-methoxy, 5-(2'-ethyl-hexoxy)-1,4-phenylene-vinylene] (MEH-PPV). The diode consists of a rectifying metal contact on the front surface of MEH-PPV film on a glass or poly(ethylene terephthalate) substrate partially coated with a layer of indium-tin oxide (ITO) as the ohmic contact. Light from a light emitting diode (LED) appears yellow-orange, with thinner polymer films producing slightly more yellowish color. Dr. J.L. Oudar of the Centre National d'Etudes des Telecommunications, France, reviewed studies of nonlinear interferometric structures that include two mirrors and a GaAs multiple quantum well (MQW) nonlinear medium in a single crystal. In these very compact nonlinear microcavities (typically 5 μm overall thickness), optical bistability is observed at mW optical power with a high contrast in the reflection mode. Other papers discussed ultrafast optical nonlinearities of semiconductor quantum wells and their application to high speed switching (N. Peyghambrian, University of Arizona, Tucson); absorption and emission spectra of various oligothiophenes (E.E. Havinga, Philips Research Laboratories, Eindhoven, The Netherlands); vapor deposition of one-dimensional conjugated polymer films (Tetsuzo Yoshimura, Fujitsu Laboratories, Ltd., Atsugi); photorefractive effects in crystals of 2-cyclooctylamino-5-nitropyridine) doped with small amounts of 7,7,8,8-tetracyanoquinodimethane (TCNQ) (K. Sutter, Institute of Quantum Electronics, Zürich); nonlinear optical properties of sol gel thin films doped with organic molecules (M. Ito and S. Hoshino, Sumitomo Electric Industries, Yokohama); surface plasmon field enhanced Raman spectroscopy in the CH stretching vibrational range (2,800 to 3,000 cm^{-1}) of cadmium arachidate multilayer assemblies (H. Knobloch, Max Planck Institüt Für Polymerforschung, Mainz, Germany); and optical limiting based on reverse saturable absorbers (J.L. Arthur, U.S. Army Vulnerability Assessment Laboratory, White Sands Missile Range, New Mexico).

GENERAL DISCUSSION

At the end of the presentations, a panel discussion was held to summarize the general views of the participants about the status of the technology and suggestions of the directions in which future research should be directed. Dr. Sasabe, in an overview, stated that during the previous years there had been a number of meetings on nonlinear optics and the materials issues. At RIKEN, the MITI program on Nonlinear Optics and Advances in the Polymer System was coming to an end. He felt that the phthalocyanines, which appeared to be the favored material for study, had a considerable potential for photonic and electro-optical applications. At the American Chemical Society (ACS) meeting held in August 1991 in the United States, more than 50 papers were presented on chromophores, poled polymers, and sol gel matrices for photorefractive materials.

All these activities indicate the great attraction of the scientific community towards organic nonlinear optical materials as the key to future photonics. Last year the 3M Company announced a new blue light laser. It is interesting to note that Bell decided to end NLO research. But Japanese scientists have been very active in the field since 1982 and expect a great future for this emerging technology.

The panelists were asked the following questions:

(1) What is the main target?

(2) How long will it take?

(3) What are the main difficulties to overcome?

Burland stated that the frequency doubler was the most important application. It should be accomplished within 2 to 3 years. The blue light laser was the major competition. Electro-optical materials for switching and modulating must also be developed within the next 2 to 3 years. In the next 2 to 3 years 2-3 GHz switches would be needed. Khanarian said that poled polymer films had long range potential for low cost integrated circuits. Making large sheets of poled polymer films for displays has a lot of potential. Shuto stated that there were a large number of researchers at NTT who were involved with NLO investigations, including SHG materials, optical phase conjugation, and optical computing. All had high hopes for organic NLO materials. Yoshimura said that his company had three researchers working on optical switching. Miyata said that most companies were concentrating their research on second order nonlinear organic materials. The major difficulty of epitaxy had to be solved. Sasabe said that his laboratory was involved in using clusters in molecular beam epitaxy to make layer-by-layer deposition of films. In these films single molecules are aligned up to a certain thickness. For example, phthalocyanine molecules are aligned up to five layers. After that they are not aligned.

Major technical barriers stated by the participants include low stability of materials in the presence of light and other environments, less than satisfactory transparency and stability in frequency doubling devices, connecting optical fibers, preparation of defect free large single crystals and their cutting and polishing, and material availability in general. Prof. Gunter stated that lithium niobate was quite stable and very good for waveguides in devices, but the blue laser was on the horizon and may present tough competition. In the theoretical area, the present theories of β, $X^{(2)}$, and $X^{(3)}$ are quite useful for guidance. But better models were needed.

For commercialization of some of the potential devices, more time and marketing have to be taken into account.

CONCLUSIONS

The main consensus was that research in the area of NLO organic materials is important as these materials have considerable potential for future photonic requirements. Major areas for additional emphasis include synthesis and preparation of single crystals and thin films of novel organic materials (using economically feasible processes); improvement of their stability, hyperpolarizability, and nonlinear optical efficiency; minimization of optical absorption for increasing the frequency doubling efficiency; and better theoretical models.

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U.S.-INDIA WORKSHOP ON FRONTIERS OF RESEARCH IN POLYMERS AND ADVANCED MATERIALS

Recent advances in polymer research as presented at the workshop are discussed.

by Iqbal Ahmad

BACKGROUND

An International Conference on the Frontiers of Polymer Research was held in Delhi in January 1991. The Army Research Office Far East (AROFE) was one of the sponsors. Because of the instability in the Gulf region, a number of important contributors to the conference could not attend. In spite of this there was considerable enthusiasm and interest in the advances in polymer research discussed at the conference. At the conclusion of the conference it was the general consensus that contributors who could not come to the conference be provided an opportunity to report their work at a workshop. So Dr. J.K. Nigam, Director of the Shriram Institute, Delhi, and Prof. P.N. Prasad, Director of the Photonic Laboratory, State University of New York, Buffalo, organized the U.S.-India Workshop on Frontiers of Research in Polymers and Advanced Materials at Goa on 6-9 January 1991. It was cosponsored by the Army Research Office Far East (AROFE) and the Shriram Institute. In all about 30 persons participated. The Proceedings will be published. In the following, only highlights of the workshop are briefly described.

DISCUSSION OF THE WORKSHOP

After the welcoming remarks by Dr. Nigam and introduction by Prof. Prasad of the scope of the workshop, Dr. S.Z. Qasim, a member of the Planning Commission of R&D in India, formally inaugurated the workshop. Qasim is Director of the Indian Institute of Oceanography, Goa, and personally led the Indian research team to Antarctica last year. Mr. Dutt of the American Embassy in Delhi then described briefly the Indo-U.S. collaborative program. He stated that currently there were almost 200 ongoing projects in India, in which the Office of Naval Research (ONR), Naval Research Laboratory (NRL), National Science Foundation (NSF), Air Force Office of Scientific Research (AFOSR), and Department of Energy (DOE) collaborate with Indian scientists. These projects are supported by the Indian rupee fund to the tune of 200M rupees (about $8M). At this workshop a team from the Air Force consisting of Dr. Charles Lee (AFOSR), Dr. Ed Helminiak [(Wright Research and Development Center (WRDC)], and COL C. Dymek [European Office of Aerospace Research and Development (EOARD)] came to explore how AFOSR could tap the scientific resources of India with the help of Indian funds.

The workshop consisted of 10 sessions covering structural polymers, conducting polymers, polymers for integrated circuits (ICs), nonlinear optical polymer molecules, polymers for aerospace applications, and polymer waste disposal.

Dr. C.K.N. Patel of AT&T Laboratories, in his keynote speech, gave an overview of polymers for photonics and electronics. He stated that the revenues from silicon-based electronics exceeded the oil revenues of the world and that silicon would continue to dominate the IC market for a long time. He projected that by 1995 the feature size of microelectronic ICs will be smaller than 0.3 micron, and the 64-MB DRAM will be commercialized by the end of the century. He explained the concept of "factory in bottle," which is essentially a new concept in which all operations on the substrate from the start to the finished state of the IC will be conducted without taking the substrate out of the controlled atmosphere at any time. He described the future potential of silicon-based polymers, particularly the polysylenes, which have a sheetlike structure and can be used to provide films of controlled refractive index and insulation properties.

The session on structural polymers was chaired by Dr. Helminiak, who is Chief of the Organic Polymers Branch at WRDC. In this session Dr. Bruno Fanconi of the National Institute of Standards and Technology (NIST), speaking on the issues and opportunities in high performance structural polymers, highlighted the critical barriers in the area of intelligent processing. He stated that the critical barriers

were the processing time, cost, and the durability of high performance polymers. He reviewed some of the ongoing work at NIST. This included modeling of the reaction injection molding of large composite components, which could be 30 to 40 feet long when used in advanced aircraft that are being designed for flying at 2.5 mach at a height of 30,000 feet. According to Fanconi, the challenges in these technologies include modeling of infiltration of heterogeneous preforms, three-dimensional (3D) flow, nonisothermal chemical reactions, and nonlinear rheology. Process monitoring is another area of importance. Aromatic heterocyclic polymers were the subject of the talk by Bob Evers of WRDC. He described studies of the application of high performance polymers in advanced aircraft such as the AV88, which is a modified version of the British Harrier. He said that while F-15 and F-18 aircraft contained 2% and 10% nonmetallic materials, AV88 had 27% organic polymers and their composites and predicted that future advanced fighter aircraft may have as much as 40% nonmetallic materials. He briefly discussed the polybenzothiozole (PBT) developed under Air Force contract and now picked up for further development by DuPont. Another new polymer that is under development at WRDC is benzocyclobutene, which shows thermal stability up to 500 to 600 °F. Blends of benzocyclobutenes and bismaleimide also show considerable thermal stability. One of the newest and most promising polymers that is drawing considerable attention is 6F-PBOs, which is a polybenzooxazole. Recently new synthesis processes of this polymer both by the Japanese and IBM have been reported. Evers also presented some experimental data on molecular composites, such as nylon plus 60% PBT. This composite has superior elasticity and strength, but low elongation. Commenting on the thermoplastic polymers, he said that the problem areas were high cost and low use temperature.

Prof. Alan MacDiarmid, the coinventor of the first conducting polymer series, polyanilines, gave an excellent overview of the state of the art. He said that the research activity on conducting polymers was increasing very rapidly. For example, in 1991 the number of patents granted was as high as 281 as compared with 106 in 1986. Also during the last 12 months, Allied Signals has started manufacturing blends of polyanilines, which make them available to researchers in larger quantities. This should accelerate the progress of this potentially very fertile field. MacDiarmid described his latest results on the synthesis of high molecular weight polyaniline. However, the data shown did not indicate any dramatic improvement in the electrical conductivity with the increase in molecular weight. Prof. Epstein of Ohio State University, who holds a dual position as Professor of Chemistry and Professor of Physics and is at the same time Director of the Materials Research Center, gave a stimulating paper on the electrical conductance and magnetic susceptibility of polymers and discussed the synthesis and properties of deca-methylferrocene, which he codiscovered with one of his graduate students. The compound had a T_c of 4.8 K. New compounds such as $V(C_6H_6)_2TCNE$ synthesized by his group have shown a T_c of 35 K, which is very encouraging advancement in the field of magnetic polymers. Prof. James Mark of the University of Cincinnati presented results of his study on high performance films from semiflexible polymers, and Dr. Nigam reviewed the synthesis and market trends of inorganic fibers used in the polymer industry either as fillers or reinforcements.

In the session chaired by Dr. Dymek (EOARD), two interesting papers came from the Indian laboratories. Dr. Mittal from the Bhaba Atomic Research Center, Bombay, described a new radiation-induced polymerization technique in which redox reactions can be induced in sensitive biosystems by exposing them to a gamma ray source, without the danger of introducing any contamination from the products of reaction. Mittal described a number of applications in which this technique was used. One of the most interesting was the development of a fast and cheap technique for detecting bilirubin needed to test for hepatitis. According to Mittal, it was almost like a litmus paper test and did not cost more than 50 pisa (2 pennies per test kit). The test kits have been distributed in a large number of Indian villages. Dr. Lal, Deputy Director of the National Physical Laboratory, Delhi, reviewed the various advanced analytical techniques available at his laboratories for the characterization of materials.

Photonics was the focus of the session chaired by Dr. Gallagher Daggit of the United Kingdom. Prof. Prasad gave a review paper on "Molecular Materials and Structural Property Relationship for Photonics." He stated that photonics is essentially light wave technology, used for processing and storing of information. This includes optical transmission, optical sensors, lasers, and photoactive components. The advantages of using photonics instead of electronics for data processing and storage include faster speed, larger volume of information processed, and insensitivity to electromagnetic interference. For optical switching required for optical processing of information, one needs to use nonlinear optical effects that allow the manipulation of light propagation by the application of the electric field or laser pulse. In addition, nonlinear optical effects give rise to frequency conversion such as frequency doubling for high density optical data storage and image analysis. Prasad discussed some of the work of his laboratories on PBT and polyphenylene vinyl (PPV). The latter polymer film on stretching develops molecular

orientation, which influences the third order nonlinear coefficient. Prasad's group has developed a sol gel process for preparing silica polymer composite, which has a combination of superior low loss transmission character of glass and high third order nonlinear coefficient of the polymer. The sol gel technique used is described in his paper reported in the Materials Research Society (MRS) Symposium Proceedings Volume 175. While MacDiarmid and others discussed polymers in which the electrical conductivity depends on the presence of delocalized pi electrons, Dr. Höchstrasse of the University of Pennsylvania described the mechanism of conduction of poly-di-hexyl-silane in which the conductivity is due to the delocalized sigma bonds and the presence of rigid segments. Prof. Larry Dalton of the University of Southern California, Los Angeles, gave an excellent paper on the photo-induced *micropatterning in organic* polymers. The major message of his talk was that through photo-induced cross linking certain polymers, such as azobenzenes, show as good or better nonlinear optical behavior than the inorganic nonlinear optical materials such as lithium niobate. This is an exciting result for researchers engaged in developing nonlinear optical organic polymers.

Dr. Krishnamurthy of the Vikrim Sarabhai Space Center, Trivandarum, described some of the laboratory facilities at his center and stated that most of the polymers and composites used in the two-stage launch rocket for placing Indian satellites in space were manufactured by the center, either in their own laboratories or on contract with the Indian industry. He stated that his laboratory had excellent capabilities in organic synthesis. Although they were not doing too much in conducting polymers, as in the context of the Indian environment, these materials are not in demand; however, some work done in basic synthetic chemistry was relevant. One of the outstanding efforts reported by him was that of Dr. Venkatachalam, who has synthesized a 3D pthalocyanine polymer. This polymer is expected to have unique properties, which are being investigated. Dr. Singh of the National Aeronautical Laboratories, Bangalore, described the facilities of the institute for the fabrication and testing of organic polymer composites needed for aircraft structures. Finally, in the concluding talk, Dr. Dhabolkar of the Shriram Institute gave an interesting exposé of the subject of polymer waste disposal. He stated that unlike developed nations, there was no major polymer waste in India. In fact, keeping in mind the low living standards of India, some of the waste products such as old tires, which are disposed of by incineration in developed countries, can be used in India in many ways. For example, they are used in village carts and then as shoes for the villagers. He pleaded that developed nations must keep in mind the needs of less developed nations when they embark on large waste disposal programs. In the case of polymer waste disposal, their approach may not be applicable to third world countries.

CONCLUSIONS

In the concluding panel discussion, which was chaired by Dr. Charles Lee of AFOSR, the major topic discussed was the opportunities for U.S.-India collaborative research, in which the rupee fund could be used effectively. Lee stated that AFOSR would like to participate in the collaborative programs with Indian scientists, as ONR and NSF are doing. Such projects should be mutually beneficial. He encouraged the Indian scientists to contact AFOSR, indicating their expertise and ideas for collaboration. AFOSR would get them in touch with the right persons in their research laboratories. They could then jointly develop a research proposal, which would be evaluated for technical merit and relevance to the needs of *India and the AFOSR programs*. Such proposals will be limited to only basic research areas, which would minimize problems related with intellectual property rights. In developing such proposals, if there is a need for an Indian scientist to visit an Air Force laboratory, it could be arranged through the EOARD Window on Science program. I represented the position of ARO and promised to explore with ARO participation in a similar manner in areas of research that are relevant to the research and development (R&D) programs of the Army. Dr. Lee also offered to coordinate with ARO as the joint program evolved and refer proposals (Indo-AFOSR) to ARO for information, cosponsorship, or ARO show of interest.

Dr. MacDiarmid offered suggestions in which Indian scientists can initiate new projects. The suggestions included synthesis of derivatives of known advanced conducting polymers and study of mechanisms and properties. Dr. Prasad suggested chemical synthesis of nonoptical organic materials and the study of their property structure relationship. Some of the characterization may need sophisticated equipment, which may not be available in India. The collaborator in the United States would work in that area.

On the whole, the attendees of the workshop, particularly the Indian scientists, were very enthusiastic about the collaborative program. From the triservice point of view, it is a window of opportunity, as with little effort and almost no dollar investment highly qualified scientists in India can be made available to work on selected Department of Defense R&D programs. Indian scientists are very good at theoretical studies because of the very high standards of education in mathematics. They are also very well versed in chemical synthesis, computer software, and theoretical physics. These resources can be effectively utilized to the mutual benefit of the two countries.

A LOOK AT PULSED POWER RESEARCH IN JAPAN

Observations from a recent visit to several Japanese industrial companies and organizations involved in pulsed power (especially rail gun) research are summarized. The number of Japanese organizations pursuing this line of research is quite surprising. Most of the work is similar to that in the United States, but in a few cases there were some unexpected and impressive performance parameters (e.g., $v > 7$ km/s for a rail gun and very high performance solid state power switches). The reason for the high Japanese interest in pulsed power research remains somewhat of an enigma.

by M. Kristiansen

INTRODUCTION

I was recently invited to present a 3-day series of lectures (14-16 November 1991) on pulsed power technology at Aso-Ikoinomura, Kumamoto Prefecture (Japan's largest national park). Before the lectures I had the opportunity to visit some Japanese universities and industrial laboratories engaged in related work. It is interesting that the lectures, which were sponsored by the Institute of Electrical Engineers of Japan and organized by Kumamoto University, were also supported by 13 large industrial firms. These were: Asahi Chemical Industry, Fuji Electric Corporation, Hitachi, Ishikawajima-Harima Heavy Industries, Japan Steel Works, Kawasaki Heavy Industries, Kobe Steel, Mitsubishi Electric Corporation, Mitsubishi Heavy Industries, Nichicon Co., Nissin Electric Co., Sumitomo Electric Industries, and Toshiba Corporation. I believe that it is very unlikely that any such set of lectures could be sponsored by such an impressive and varied group of U.S. industrial organizations, no matter who gave the lectures. U.S. firms would decide up front that this was a topic of no interest to them, whereas Japanese firms want to make sure that they do not overlook a new field or opportunity. The lectures were attended by 59 people from 25 different organizations.

I was also surprised to learn that the Institute of Electrical Engineers of Japan has an active subcommittee on Applied Technology for Electromagnetic Mass Acceleration, and I had the pleasure to be hosted by them one evening in Tokyo. This committee has members from industry, universities, national laboratories, and the Japanese Defense Agency. There are strong Japanese interests and activities in various aspects of electromagnetic launchers (EMLs), and much of this report will be related to EML research. This research is mostly related to armor testing by companies, such as Japan Steel Works, in the hope that the Japanese Defense Agency will initiate a major program in this field.

TECHNICAL VISITS AND OBSERVATIONS

In the following I will summarize the technical observations I made at some Japanese industrial and university laboratories in the order in which I visited them. Representatives from many of these institutions have visited our laboratories at Texas Tech over the past few years, some for extended periods of time, so I was already reasonably familiar with the main theme of their work.

Toshiba Corporation, Fuchu Works

This is, of course, one enormous corporation with a total of some 70,000 employees in the main company and over $30B in annual sales. The Fuchu Works employs some 7,500 people, with another 5,500 in the company's subsidiaries. The staggering fact is that 60% of the employees are engineers and 25% are assembly workers. I do not have the facts from similar industries in the United States or Europe, but I find it hard to believe that any of them has this high a percentage of engineers.

I had, on a previous occasion, visited Toshiba's Hamakawasaki Works and was familiar with some of its circuit breaker and vacuum interrupter work. I was met by representatives from both places and it is difficult for me to separate the exact responsibilities of each

place. My thanks go to Drs. K. Sugi, E. Kaneko, H. Ohashi, K. Hoshi, I. Ohshima, and K. Okamura.

Toshiba Corporation is a leading manufacturer of high voltage systems and switch gear and I was especially impressed by the latter aspect. Suffice it here to say that Toshiba's continued effort of reducing the size of the equipment is truly remarkable. Its vacuum interrupter work is also outstanding and it has been the leading organization in increasing the interruption current and voltage of these devices while continually reducing their sizes. This is achieved by clever electrode configurations and special electrode materials. The production of these devices increased by a factor of 14 in the period 1970-86, whereas U.S. industry basically dropped out of the competition.

Of special interest was the development of a wide range of high power semiconductor switches. Among these devices were 3-kV, 9-kA; 5-kV, 4-kA; and 6-kV, 3-kA gate turn off (GTO) transistors. For the first device a dI/dt of 8 kA/μs was reported. A nationally sponsored [Ministry of International Trade and Industry (MITI)] project on metal oxide semiconductor (MOS) assisted gate triggered (MAGT) thyristors has a design goal of 2.5 kV and 10^{11} A/s-cm^2. They have achieved a current density of 2 kA/0.14 cm^{-2} and operated at 5 kHz. These devices have low losses and require low trigger power. Figure 1 shows a convenient diagram for comparing the operating regimes of various types of high power semiconductor switches. Toshiba has done considerable, successful work on series-parallel connection of these devices. The company also reported the development of a new amorphous (cobalt based?) metal with much lower loss, but lower saturation magnetic field, than Metglas (registered trademark of Allied Chemical). The new material is presumably available in 25-μm-thick foils. The greatly reduced losses in this new material may make it very attractive for many repetitive pulsed power applications, such as isotope separation and NOX/SOX removal from flue stacks.

Tokyo Institute of Technology at Nagatsuta

Dr. Koichi Kasuya has for many years worked on ion beam generation from cryogenically cooled (liquid nitrogen) anodes. The institute has a series of PICA (particle beam inertial confinement fusion apparatus with cryogenically refrigerated anode driver) machines in use for this work. The goal is to obtain high purity, high current ion beams for inertial confinement fusion (ICF). The PICA-4 machine, for instance, is a 3-Ω, 120-ns, 1.5-MV machine. The anode is covered with D_2 or ammonia ice, and the best results seem to be a few kA current at a few 10s A/cm^2 current density. The institute also does laser development work with equipment provided by industry. In all cases the work was sufficiently far from my own area of expertise that it was difficult to judge its quality.

Ishikawajima-Harima Heavy Industries (IHI) Co., Ltd., Yokohama

My hosts at IHI were Drs. K. Uematsu, S. Morimoto, T. Majima, and T. Tagaeto. This is again a very large company with many employees (~15,000 in 1988) and numerous activities in the heavy construction field, such as nuclear power plants, ships, oil drilling platforms, manufacturing machines, bridges, etc. My visit was to its research institute. Of particular interest to me was the arcjet and EML work. The configurations of the magneto plasma dynamic (MPD) and arcjet thrusters for electric space propulsion were fairly conventional. The institute's published work on arcjet thrusters at recent international conferences has been concerned with low power (0.5-1 kW) H_2/N_2 and simulated hydrazine (N_2 + $2H_2$) devices. The reported performance has not been anything unusual. The researchers claim, however, that a barium oxide impregnated tungsten cathode has less erosion than other materials, e.g., thoriated tungsten, in their 8-kA, 600-μs, 1- to 2-pps MPD generator. This is quite interesting since we have the opposite experience in continuous arcjets at ~200 A. This could be due to variations in the impregnation process, but it needs further study.

They have also used the arcjet to produce diamond film with a very clean, narrow Raman spectrum. In this case they inject H_2 + Ar in the conventional way from the rear of the device and inject CH_4 in the nozzle section. The film is deposited on a Mo (1,000 °C) substrate. The deposition rate is 1.5 μm/min for an arcjet power level of 2-5 kW. The back pressure in the chamber is 20-100 Torr and the plasma jet then does not expand enough to produce large area films. Five Japanese companies are apparently engaged in similar work.

IHI's EML (rail gun) was of a conventional design, superficially similar to the one described in the next section. In both cases the entire gun assembly was submerged in vacuum. Apparently the results were not as good as those reported in the next section of this report, and the reason for this was not obvious.

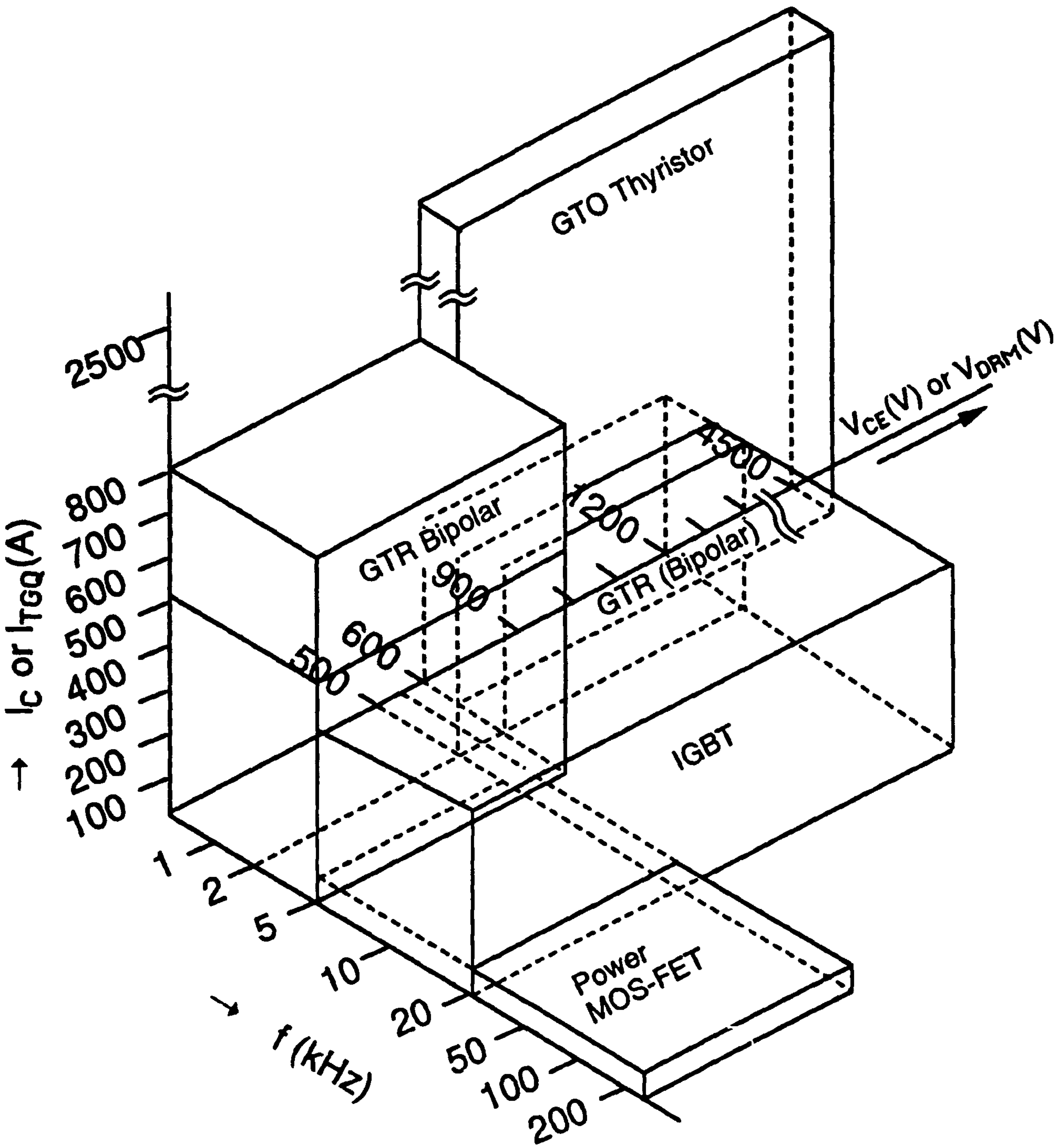

Figure 1. Operating regions for various semiconductor devices [reprinted with permission from K. Okamura, E. Kaneko, et al., "Pulsed power and industrial application," *J.I.E.E. Plasma Research* EP-91-57, 35 (1991)].

The Institute of Space and Astronautical Science, Kanagawa

Professor N. Kawashima was my host during this visit. This institute has a very interesting rail gun in terms of its performance. The basic system appears fairly conventional, as shown in Figures 2 and 3. The 2-meter-long gun has a nominal bore of 1.3 cm. The rails are made of copper and the insulator of polycarbonate. The whole rail system is enclosed in a vacuum tank evacuated by a rotary vacuum pump. No preinjection is used. The interesting claim is that the researchers achieve 6 km/s velocity for a 0.9-g projectile "stably" and 7.5 km/s in "some cases." This is, indeed, quite impressive. In the United States 6 km/s is considered a "velocity barrier," which is under extensive investigation. There have been a few, unverified reports of a few shots with v > 7 km/s, but not on a repeatable basis.

It is not clear why this device has such excellent performance except that they disassemble and rebore the gun after each shot. Each time they bore off 0.5 mm. Extreme care in assembly and rebore seems to be the only explanation they could give.

The system operates at 2 shots/wk and is mostly used for micrometeorite and space debris impact simulation studies.

Kumamoto University

Dr. Hidenori Akiyama has cooperated with our research group for several years and has spent considerable time in our laboratory. We have coauthored several publications and he was the main organizer of my lectures and laboratory visits. He has an excellent, small research group that utilizes space and facilities to the fullest. His interaction with students and staff is most cordial and there is evidence of excellent group spirit and enthusiasm.

The university's ASO I and II machines have produced very interesting plasma opening switch results with very modest size facilities. This type of opening switch is of considerable interest both in the United States and in Russia, where the latest nuclear weapons effects simulators under construction depend critically on the success of such switches. These switches are equally important to inertial confinement fusion devices. Akiyama and his group have shown that it is possible to do meaningful work in this field with modest, university-size machines. They have, for instance, demonstrated a factor of 12 voltage gain (from 30 to 400 kV) at 80 kA with 10-ns risetime using a two-stage opening switch with a first-stage fuse followed by a plasma opening switch (POS).

A very interesting concept is the use of a laser-produced plasma, on a rotating graphite target, to achieve high reproducibility and long life. They are in the process of upgrading the laser from 1 J to 30 J/pulse to get higher currents than the 20 kA they get with the 1-J laser. High reproducibility and long life are critical parameters for all the intended applications of such switches.

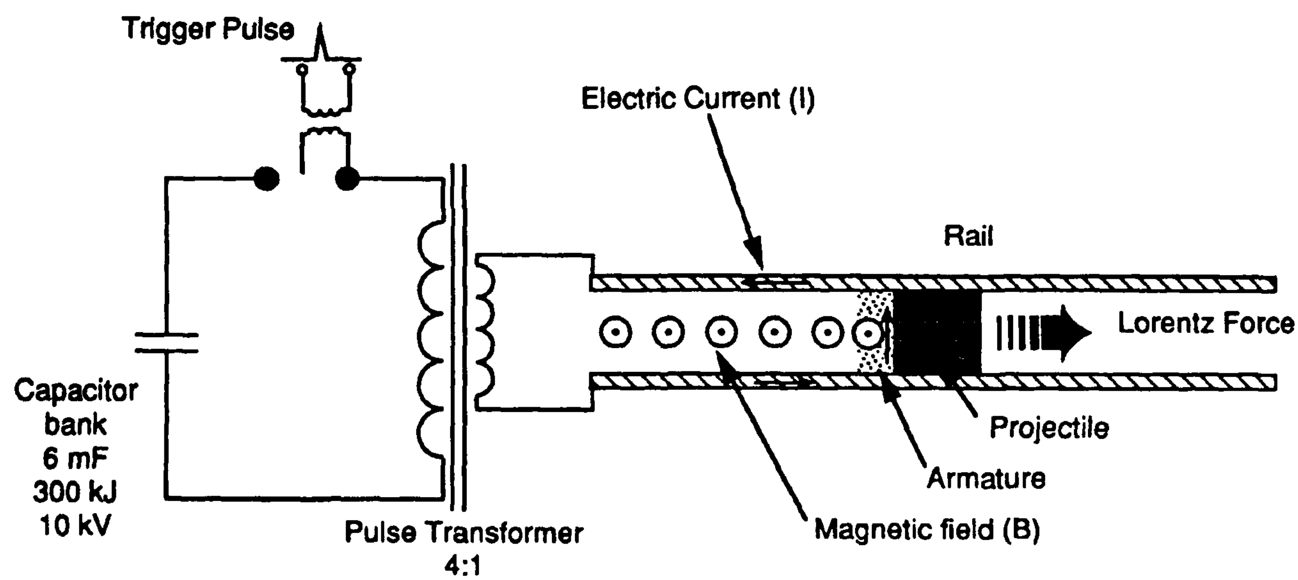

Figure 2. Schematic layout of ISAS rail gun "HYPAC" system. Adapted and reprinted with permission from A. Yamori et al., "Rail gun experiment (HYPAC) at ISAS," *IEEE Transactions on Magnetics* 27(1), 120-129 (1991). © 1991 IEEE.

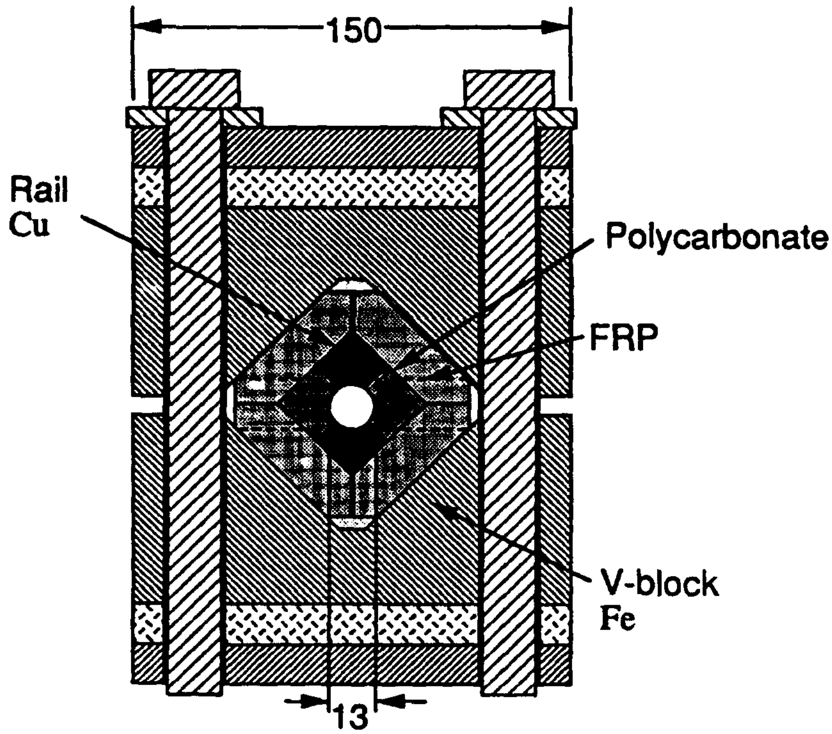

Figure 3. Cross section of the rail gun. Adapted and reprinted with permission from A. Yamori et al., "*Rail gun experiment* (HYPAC) at ISAS," *IEEE Transactions on Magnetics* 27(1), 120-129 (1991). © 1991 IEEE.

Other work includes z-pinches to produce soft x-rays and also plans to use gas puff pinches as closing and opening switches, utilizing magnetohydrodynamic (MHD) instabilities for the opening phase. They have numerous applications in mind for the ASO I and II machines and have, for instance, demonstrated their use to drive a virtual cathode oscillator (Vircator) to produce 100-ns pulses of 1- to 6-GHz microwaves. This is the most compact overall Vircator system that I have seen in either the United States or Russia. At the present time they are conducting feasibility studies for the use of these machines to make a free electron laser (FEL).

In cooperation with the National Institute for Fusion Studies at Nagoya, they are investigating the feasibility of using a rail gun to accelerate hydrogen ice pellets for injection into and refueling of fusion plasmas. The acceleration force in a conventional rail gun is proportional to the product of the current and the self-induced magnetic field. By applying an external, permanent magnetic field of 1 T they hope to reduce the required rail current and thereby the rail erosion and the resulting impurity injection into the fusion plasma. The goal is a velocity in excess of 3 km/s for a 0.3-g mass in a 1-meter-long rail gun. A similar effort at Mitsubishi Heavy Industries, Ltd. is described in the next section of this report.

Much work is also underway on gas discharge phenomena. This includes dc glow discharges in flowing gas systems for laser excitation and plasma processing. Another effort of great personal interest is the work on pulsed arc discharge resistance measurement. This is the primary area of our recent cooperation and is a very difficult measurement of importance to developing low loss, high repetition rate spark gap switches. A "hobby" experiment of Dr. Akiyama is an effort to trigger lightening discharges using long water spouts. Some very interesting and unexplained laboratory results have been obtained so far.

All in all, this is a very productive university research group with lots of ideas and experiments and they seem to have a great deal of fun doing it.

A surprise to me was the visit to the High Energy Rate Laboratory at Kumamoto University (Dr. T. Mashimo). This laboratory has facilities for doing explosives work and high velocity powder gun experiments **on campus.** I am only aware of two universities with such facilities in the United States and these are rather remotely located. An interesting concept also being studied here is a high velocity centrifuging experiment to produce new materials by sedimentation in condensed matter. The process is apparently proprietary and could not be discussed in detail. A paper by Dr. Mashimo [in *Phys. Rev. A* 38, 4149 (1988)] gives some of the background theory.

Mitsubishi Heavy Industries, Ltd., Takasago Research and Development Center

Drs. S. Kuribayashi, K. Asada, and K. Azuma were my hosts. This is again a large research center that is part of a very large corporation. The work at the center covers a wide range of topics, such as breeder reactors, fusion reactors, robots, turbomachinery, environmental control, space technology, control technology, and manufacturing technology. The center is part of the U.S.-Japan cooperative program on a tritium system test assembly. I visited the Applied Physics Team, where

Dr. Y. Matsumoto is the director; unfortunately, he was absent.

The team also is working on a rail gun system for hydrogen ice pellet injection in fusion plasmas (see the previous section). They want to accelerate 3-mm-diameter, 3-mm-long ice pellets, but they are presently experimenting with plastic projectiles. A novel aspect was the use of a laser to ignite the rail gun discharge in an effort to increase reliability and life of the device. The system is intended for use on the JT-60 Tokamak. The results, so far, are inconclusive. They want to use yttrium oxide doped tungsten in the rails to decrease the work function and hence the erosion and injected impurities. The current level is approximately 20 kA, and they use an injection velocity of 300 m/s to obtain a maximum velocity of 2.3 km/s. They cooperate with Professor A. Sawaoka at the Tokyo Institute of Technology on this work.

A conventional, square bore rail gun with no preinjection velocity, is driven by a 250-kJ, 20-kV capacitor bank via an 8:1 transformer to get 1 MA current. The gun is disassembled after about 10 shots. The exit velocity for a 1-cm by 1-cm, 4-g projectile is about 3 km/s. This is a "university size" experiment, similar to one in our own laboratory (actually somewhat smaller than ours).

A 50-kJ electrothermal gun with capillary discharge accelerates 1-g projectiles to 1 km/s, but they have severe problems (as do others) with radially induced stress cracking in the insulator. Their next plan is for a 500-kJ electrothermal gun accelerating 10-g projectiles to 3 km/s and then hopefully on to a 1-MJ experiment. They claim to have excellent computer codes for projectile impact studies that they compare with their experimental results. Their interest at this time, unless the Japanese Defense Force initiates a new program, seems to me more as a user of these devices for shock physics and impact studies rather than in the devices themselves which, except for the ice pellet injector, were rather conventional in design and results.

Other work of interest in this group includes the development of large CO lasers for metal cutting. They now have a 10-kW unit and plan to go to 20 kW for cutting stainless steel plates up to 30 cm thick. This would have application to the disassembly of old pressurized water nuclear reactors. Studies are underway on a free electron laser in the infrared regime using a 70-MeV accelerator. Work is also in progress on ion thrusters for space propulsion.

SUMMARY

After several visits to Japan over the past 15 years, I remain both surprised and impressed by both the quantity and quality of pulsed power research and development in Japan. In the United States this line of work has mostly been supported by the Department of Defense or the nuclear weapons side of the Department of Energy and similarly in the United Kingdom and Russia. This is obviously not the driving forces behind the work in Japan, and I remain somewhat puzzled as to the driving force and motivation behind the Japanese work. We are all, obviously, looking very hard for industrial applications, but these have been very slow to develop. A particular surprise to me was the proliferation of and interest in electromagnetic launchers. Time did not permit me to visit all these EML facilities (e.g., Japan Steel Works has its facilities at Hokkaido), but I would like very much to make another visit to Japan devoted primarily to EML facilities. Cooperative efforts in this field could prove to be very fruitful.

ACKNOWLEDGMENT

I want to thank Professor Hidenori Akiyama of Kumamoto University and Dr. Kazunari Ikuta of Japan Steel Works, Ltd., who were instrumental in organizing my lectures and visits and arranging for helpful and competent guides at all places. Travel support from the Office of Naval Research is greatly appreciated.

M. Kristiansen received B.S.E.E. and Ph.D. degrees from the University of Texas at Austin in 1961 and 1967, respectively. Since 1966 he has been on the faculty of Texas Tech University, Lubbock, where he is now the C.B. Thornton/P.W. Horn Professor of Electrical Engineering/Physics. His current research interests and specialties are plasma dynamics, pulsed power technology, and quantum electronics. He has published over 200 journal articles and conference proceedings papers, has coauthored one book, and is coeditor of a new series of books on Advances in Pulsed Power Technology. Dr. Kristiansen is a member of the Institute of Electrical and Electronics Engineers (IEEE) (Fellow), the American Society for Engineering Education, the American Physical Society (Fellow), and the American Association for the Advancement of Science. He has received the following awards: U.S. Department of the Air Force Meritorious Civilian Service Award (1985), IEEE International Pulsed Power Conference Peter Haas Award (1987), and IEEE Nuclear and Plasma Science Society Merit Award (1991).

THE FIRST ASIA-PACIFIC CONFERENCE ON ALGAL BIOTECHNOLOGY

This article presents recent research in three major areas of algal biotechnology: large sea weeds, their products, and methods of cultivation; technologies for cultivating microalgae and the products of these algae; and use of algal technologies for solving ecological and environmental problems.

by Aharon Gibor

INTRODUCTION

The first Asia-Pacific Conference on Algal Biotechnology was held from 29-31 January 1992 at the Institute for Advanced Studies of the University of Malaysia, Kuala Lumpur. The meeting was sponsored by the university, the Malaysia National Working Group on Biotechnology, and the Ministry of Science, Technology, and Environment.

There were 151 scientists from 25 countries, with the majority of these from Southeast Asia--Malaysia, Indonesia, India, China, Thailand, Singapore, and the Philippines. The remainder of the delegates came from Australia, Japan, Taiwan, Hong Kong, Sri Lanka, the United States, New Zealand, Kuwait, the United Kingdom, Sweden, Italy, Morocco, and France. The participants were from academic institutions, governmental organizations, and private companies. It was very interesting to discover the growing interest in so many countries in using algae for a variety of purposes.

Three major topics in algal biotechnology were considered: (1) large sea weeds, their products, and methods of cultivation; (2) technologies for cultivating microalgae and the products of these algae; and (3) use of algal technologies for solving ecological and environmental problems. There were 45 oral and 30 poster presentations on these topics.

SEA WEEDS

Prof. Isabella A. Abbott (University of Hawaii), the doyenne of Pacific algal taxonomy, introduced the first session. She emphasized the value of identifying the algal species and strains because of variations in the quality of their chemical constituents. For example, the quality of agar that is obtained from different strains of agarophyte differs greatly. Screening, selecting, and propagating desired plants, therefore, are important steps before mariculture can be undertaken.

Dr. Gavino C. Trono (Philippines) substantiated Abbott's points by the work in progress in the Philippines on sea weed mariculture. The important species being cultivated are *Eucheuma*, *Kappaphycus*, *Gracil'aria*, and *Caulerpa*. It is projected that up to 1 million people will be employed in the mariculture and processing of these sea weeds within 2 years.

The introduction of sea weed colloids as fat substitutes in hamburgers is anticipated to create a demand for these substances. In the Philippines the economic importance of sea weeds has already surpassed that of coconut plantations.

One of the problems being studied is the choice of strains that will withstand fluctuations in the salinity of the culture medium. Shallow seawater ponds become diluted during the rainy season and concentrated during dry spells; this is deleterious to some strains of algae. Strains that are tolerant to salinity variation will be of great advantage in such cultures.

The quality of the biocolloids being produced varies greatly with the strains being used and also with the culture conditions, such as temperature, availability of nutrients, age of the plants, and the parts of the plants that are extracted. Most of the farming is being done by vegetative propagation of branches of the algae either suspended from nets or planted in the bottom mud of shallow ponds.

An important problem is ice-ice disease, which attacks *Eucheuma* plants. The primary cause is still not known and is under investigation.

Peter Gracesa et al. (United Kingdom) presented systematic studies on agarophytic algae based on the analysis of 18S-ribosomal RNA genes. Small pieces of dried algal tissue are sufficient for DNA extraction, polymerase chain reaction (PCR) amplification, and analysis.

Other reports on sea weeds covered their lipids, heavy metal ion uptake, the quality of the biocolloid of red and brown algae, and a demonstration of antibiotics in sea weed extracts.

TECHNOLOGIES FOR CULTIVATING MICROALGAE AND THE PRODUCTS OF THESE ALGAE

M.A. Borowitzka (Murdoch University, Australia) introduced the topic by reviewing the variety of products already being derived from algal cultures. *Dunaliella* is being cultured for its beta carotene content and, along with *Spirulina*, it is being produced on a commercial scale in Australia, Italy, Israel, and the United States. *Haematococcus* produces astaxanthin. *Porphyridium* is grown for phycobilins and for biocolloids. Other algae contain hydrocarbons, fatty acids, and other bioactive substances.

A major problem in the large scale farming of unicellular algae is the control of competing organisms. *Dunaliella* has the unique advantage of the ability to grow in high salinity media where competitors are inhibited.

A number of diatoms and dinoflagellates are being cultivated primarily to serve as food in aquaculture hatcheries. Some larvae of highly valued invertebrate animals require specific algae for their normal development.

The recent interest in highly unsaturated fatty acids for human nutrition has led to studies on cultivation of some diatoms and other algae. Many of these cultures are being done not in open ponds but in closed culture chambers. New designs of such "photo bioreactors" were reported. Closed transparent tubular systems appear to be popular; both horizontal and vertically held tubular systems were described. These types of bioreactors are expensive and are therefore suitable for the production of very highly valued substances.

A number of reports on culture conditions that maximize the yield of products such as carotenoid pigments or unsaturated fatty acids were presented.

A major problem applicable to unicellular algae and not to filamentous forms such as *Spirulina* is the harvesting of the crop from a dilute aqueous suspension. Flocculation, filtration, and centrifugation are the common procedures being studied.

THE USE OF ALGAE FOR SOLVING ECOLOGICAL AND ENVIRONMENTAL PROBLEMS

The last topic was introduced by B. Whitton (University of Durham, United Kingdom). The ability of some algae to concentrate ions from the environment has led to their use as pollution detectors, especially of heavy metals. Both planktonic and benthic algae from marine and freshwater were shown to be able to accumulate some metals. Research on the most appropriate species for detecting specific elements is being conducted. In another aspect based on these properties of the algae, the species composition of the algae in a body of water functions as an indicator of the chemical composition of the water. The algal composition blooming in effluents from different mines or from ore containing soil is said to be unique for the specific metal ions that are present. Mass cultures of such metal concentrating algae are being considered for the detoxification of industrial effluents.

Whitton also indicated that microanalysis of small samples of dried algae indicated the presence of specific metals in their environment. Dried and stored herbarium specimens can, therefore, serve as good records of environmental conditions at the time of their collection and can be used for comparison to the present state of the water.

Cladophora and *Enteromorpha* are among the recommended algae for evaluation of heavy metal contamination of estuaries.

The use of algae in oxidation ponds to decompose organic pollution in industrial, farm, and domestic waste waters is an active area of research. The treatment of effluents from palm oil mills and rubber treatment plants in Malaysia is being studied. In all these studies a major goal is the recovery of purified water. A remaining problem is finding an economical method for harvesting the produced algal biomass; otherwise, the procedure just substitutes an algal biomass for the previous organic waste materials.

Another aspect of algal cultivation is encouraging the growth of nitrogen-fixing algae in farm fields. The productivity of rice fields was shown to increase in the presence of such algae. The control of noxious algae in drinking water sources is another subject of interest to environmental public health officials.

SUMMARY

Most of the reports dealt with subjects that are not new, but their application to local problems was interesting. Commercial sea weed aquaculture in this region is less than 20 years old, but it is fast growing and already significant to the economy of the Philippines. Indonesia, Thailand, and Malaysia also are rapidly developing this resource. The availability of sunshine, water, and manpower makes the region suitable for cultivating algae. The interest and enthusiasm among the young scientists from Southeast Asia who attended this conference indicate that this is indeed a growing enterprise. It reflects the general spirit of this rapidly growing region. With the development of new markets for algal biocolloids, I foresee rapid development of this area of marine biotechnology in the near future.

For more information on this conference, please contact the organizer:

Dr. Phang Siew Moi
Institute for Advanced Studies
University of Malaysia
59100 Kuala Lumpur

Aharon Gibor completed a 1-year assignment at the Office of Naval Research Asian Office in September 1990. Dr. Gibor is a professor of biology at the University of California, Santa Barbara. He received a B.A. degree in 1950, his M.A. degree in 1952 from the University of California, Berkeley, and his Ph.D. degree in 1956 from Stanford University. His thesis research was done at the Hopkins Marine Station. Dr. Gibor was involved in research on the genetic autonomy of cytoplasmic organelles of eukaryotic cells, especially chloroplasts and flagella. His present research is on the growth and development of algal cells and tissues and the role of cell walls of these plants in controlling their development.

TECHNICAL ASSESSMENT OF TWO UNMANNED VEHICLES FOR UNDERSEA RESEARCH

Two new Japanese developments in undersea technology were evaluated during sea trials: a semi-autonomous vehicle and a new, low-light-level camera for a remotely operated vehicle. The semi-autonomous vehicle, or UROV (Untethered Remotely Operated Vehicle), was attached to the surface with a 1-mm fiber optic link. The low-light-level camera, named HARP (High-Gain Avalanche Rushing Amorphous Photoconductor), was deployed on a 3,000-meter ROV and is a next generation for underwater camera low-light capability. Both systems tested well and are assessed below.

by A.N. Kalvaitis and Gregory Stone

INTRODUCTION

Proof-of-concept sea trials of two different undersea vehicles, developed for undersea research, were observed on 6-7 November 1991. These evaluations were conducted on the UROV-500, a battery powered remotely operated vehicle (ROV), and the DOLPHIN 3K ROV, using an ultra-sensitive underwater color video camera. These tests were conducted in the western part of Sagami Bay near Hatsushima Island off Atami, Japan, using the R/V KAIYO and R/V NATSUSHIMA as surface support vessels. The Japan Marine Science and Technology Center (JAMSTEC), the primary institution in Japan dedicated to ocean research, was responsible for carrying out these investigations.

PARTICIPANTS

The authors were invited by JAMSTEC to witness these sea trials under the auspices of the Panel on Diving Physiology and Technology of the United States-Japan Cooperative Program in Natural Resources (UJNR). Mr. Greg Stone, a guest researcher at JAMSTEC, is on exchange from the National Oceanic and Atmospheric Administration's (NOAA) National Undersea Research Program (NURP). The other author, Mr. A. Kalvaitis, is a senior engineer at NOAA-NURP in Silver Spring, Maryland. Cruise participants included several engineers, among them Dr. Matsuo Hattori of JAMSTEC, and researchers from other Japanese agencies and companies.

BACKGROUND

The purpose of observing these tests was to technically assess the capability of these vehicles to satisfactorily conduct undersea research. NURP directs a program that is the United States civilian focus for meeting the undersea research requirements of government, academia, and industrial communities. In-situ facilities available to this program include manned submersibles, research habitats, and unmanned systems such as ROVs and autonomous undersea vehicles (AUVs), as well as bottom observatories.

These capabilities enable scientists to collect data, make observations, collect samples, and conduct experiments not possible within the limitations of traditional laboratory and ship-based research. Most of the research supported worldwide has been conducted from manned submersibles to depths of 6,000 meters, although there has been a trend toward the utilization of unmanned vehicles such as ROVs and AUVs (Ref 1 and 2).

UROV-500 DESCRIPTION AND ASSESSMENT

The UROV-500 is basically a tetherless, battery powered ROV that uses an expendable fiber optic link to transmit video and other data from depths to 500 meters. These tests were conducted on 6 November, near Hatsushima Island in western Sagami Bay off the JAMSTEC support ship R/V KAIYO. More detailed information on the KAIYO, a semisubmersible twin-hull ship, 61.5 meters long, that allows for

stable at-sea operations, can be found in Reference 3.

This ship, a highly capable saturation diving vessel, can also deploy the DOLPHIN 3K as well as other ROVs. The KAIYO can be held stationary during dive operations by means of a four-point mooring or by dynamic positioning. While in the dynamic positioning work mode, a computer tracking system maintains the ship's position from bottom-mounted transponders or land-based systems. Actual movement of the ship is controlled by bow and aft thrusters and the KAIYO's twin screws.

JAMSTEC has been developing fiber optic linked, battery operated, untethered ROVs since 1986. One of these systems, termed the UROV-2,000, is designed for operations to 2,000 meters and completed successful sea trials in 1990 (Ref 4). These tests demonstrated the functional ability of a self-powered, expendable, fiber optic based vehicle. The 0.9-mm-diameter fiber optics were deployed successfully, and data were collected on system performance. A maximum depth of 515 meters was reached during seven dives.

An extension of this development has been the design and construction of the UROV-500, which has a similar configuration but a depth limitation of 500 meters. This vehicle (see Figure 1) will ultimately be used for fisheries surveys in the Japan Sea off Fukui Prefecture. Two tests were witnessed on 6 November: the first successful deployment reached 300 meters, while the second achieved a maximum depth of 501 meters.

The UROV-500 was developed in a cooperative effort between JAMSTEC and Sumitomo Heavy Industries and Sumitomo Electric Industries. The vehicle is self-powered using Ni-Cd batteries and an expendable fiber optic cable to transmit video, sensor, and control signals. System components include a control van, A-frame launcher, the fiber optic cable assembly, and the vehicle itself. The fiber optic cable consists of two spoolers: one is in the vehicle and the other is on the ship. Each contains 1,500 meters of graded index (G.I.) fiber optic cable. Both can uncoil independently if there is excess loading (1 kg tension), and the operation is similar to an expendable bathythermograph (XBT). UROV-500 specifications are as follows:

Depth	500 m
Size	2 (L) x 1 (W) x 1 (H) m
Weight	450 kg
Speed	1 m/s (max) 0.5 m/s (cruise)
Batteries	Ni-Cd, 100 V 20 AH, 24 V 20 AH 2 x 500 W (F/R) 2 x 250 W (U/D)
Instrumentation	CCD color TV, black & white low-light TV, light x 3, still camera (36 exposures), strobe, temperature sensor, transponder, radio transmitter
Cable	Expendable optical fiber cable, 0.9-mm diameter, 1,500-m long x 2 (vehicle and ship)
Transmission	Three-wave length division multiple optical transmission

The first deployment was interrupted by a fault in the fiber optics. Retrieval was conducted without incident, and the cable was repaired using an optical fiber fusion splicing machine. An optical time domain reflectometer isolated the break, and it was spliced within 30 minutes after recovery. The UROV-500 was subsequently redeployed and reached a 300-meter depth. The video quality of the transmitted pictures was excellent. During launch operations, winds were 14 m/s (28 knots) and whitecaps were observed. It is theorized that these windy conditions could have contributed to the fiber optic fault.

The second trial was in the afternoon and the vehicle achieved the design depth of 500 meters. An 11-kg dropweight controlled the descent velocity (approximately 64 cm/s), and the weight dropped near the bottom. After a 45-minute survey at depths from 487 to 501 meters, the vehicle was recovered without incident. This demonstration confirmed that a self-powered vehicle, having expendable fiber optics, offers significant promise for undersea research applications.

UROV's salient features of high quality video and excellent maneuverability combine to provide a suitable platform for visual transects and inspections related to various undersea tasks. In addition, such a design configuration would provide a much larger lateral capability than conventional ROVs and allow excursions into presently inaccessible environments such as under-ice regions. Operational advantages of the UROV include the elimination of heavy duty deck handling equipment associated with typical large-diameter ROV umbilical deployments. Secondly, operational constraints associated with flow-induced cable drag typical of long, large diameter ROV umbilicals are significantly reduced.

It should be pointed out that the present fiber optic platforms developed by JAMSTEC are also being utilized as testbeds for advanced AUVs. Research is underway on communication and control methods that will allow the elimination of the fiber optic cable linking the support ship with the self-powered vehicle. JAMSTEC is developing a color video transmission system that will be capable of sending one frame per 6 seconds over distances of up to 7 km.

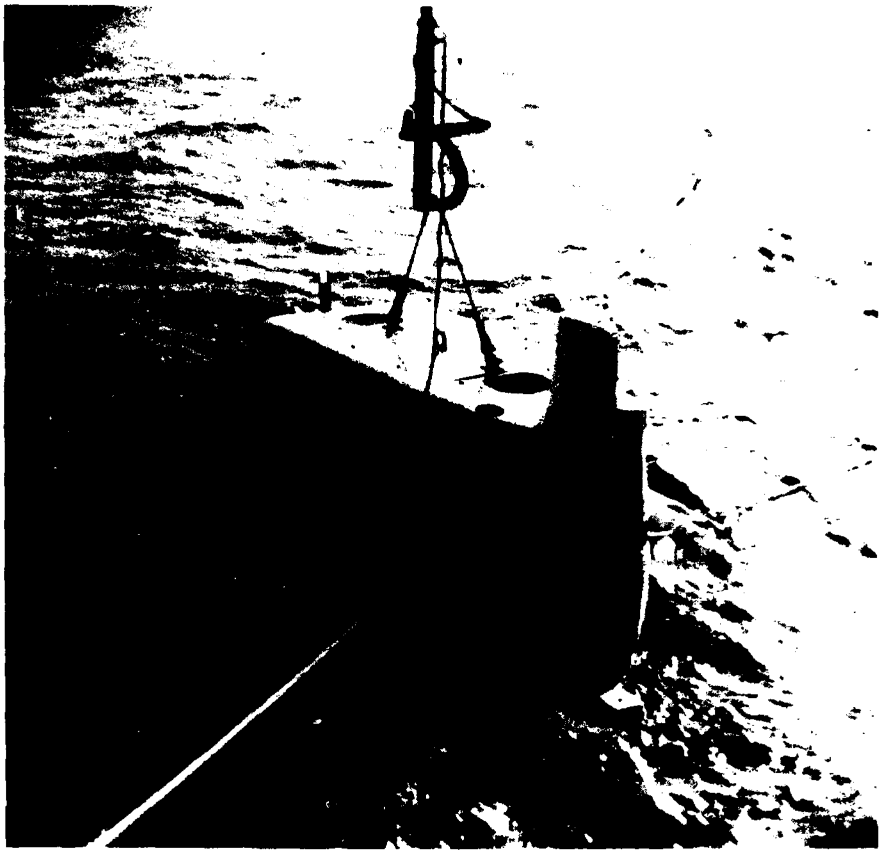

Figure 1. Deployment of UROV-500.

DOLPHIN 3K DESCRIPTION AND ASSESSMENT

The DOLPHIN 3K ROV (Figure 2) is a 3,300-meter-deep vehicle designed for undersea science applications, especially marine geological. The DOLPHIN 3K was designed and developed by Mitsui Engineering and Shipbuilding Co., Ltd. (MES) for JAMSTEC. It has been utilized since 1987 for various scientific applications to depths of 3,429 meters.

Major shipboard components include a control/navigation van, a deck handling system including a heave compensator, and a winch for the 5,000-meter-long, 30-mm-diameter ROV umbilical. ROV capabilities include broadcast quality TV video via optical fiber cable, master-slave seven-function manipulator, a five-function manipulator, conductivity/temperature/depth (CTD) sensors, and various sampling containers and tools (Ref 1).

The ROV is designed so that it can be deployed off either the R/V KAIYO or the R/V NATSUSHIMA. Another application of the DOLPHIN 3K ROV is to serve as the rescue vehicle for the submersible SHINKAI 2000 that is operated by JAMSTEC. The ROV also has been used for predive surveys in support of the SHINKAI 2000.

The DOLPHIN 3K was installed on the R/V NATSUSHIMA for test dives on 7 November, also near Hatsushima Island, for the purpose of evaluating a high-resolution, low-light-level TV camera. In addition, samples of giant clams (*Calyptogena*) were observed and recovered by the ROV sampling and collecting equipment.

Several tests were conducted. A color screen for visual experiments was deployed in 1,250-meter water depths. Various combinations of light levels and distances were verified. Distributions of *Calyptogena* communities on the seafloor were readily observed at a 10-meter range using lighting from two 500-W halogen bulbs.

SUPER-HARP COLOR TV CAMERA

JAMSTEC has sponsored development of a low-light-level color video camera for use on the DOLPHIN 3K. The camera uses three camera tubes that were designed by NHK Science and Technical Research Laboratories. This camera is termed a Super-HARP camera (High-Gain Avalanche Rushing Amorphous Photoconductor). It is theoretically 100 times as sensitive as conventional tubes; this allows not only ultra high sensitivity but also excellent picture quality, low noise, high resolution, low photoconductive lag, and no burning (Ref 5). The specifications of the Super-HARP camera are as follows:

Horizontal resolution	>600 lines
Minimum luminous intensity	0.8 lux (9 dB up)
S/N ratio	>60 dB
Outer diameter & length	ϕ 184 x 632 mm
Operational depth	>3,300 m

Another purpose of this assessment was to observe the undersea science capabilities of the DOLPHIN ROV. The ROV was efficiently deployed and retrieved using the A-frame on the stern of the NATSUSHIMA. The ROV performed video and photo survey transects 1 to 5 meters off the seafloor and collected approximately 20 clams using the manipulator and a wire mesh scoop. The clams were placed in an insulated container for further study. This same site has been surveyed extensively over the past several years using the ROV,

and there are several long-term experiments underway on the seafloor.

CONCLUSIONS

Both the UROV-500 and the DOLPHIN 3K ROV performed well during the operations observed. The UROV design, which combines fiber optic technology and onboard power, eliminated problems associated with long, bulky umbilicals. It is envisioned that various mission-specific fiber optic type vehicles will be developed in response to science needs, will be relatively low cost, and will operate in areas inaccessible to manned submersibles, i.e., under ice environments. This design configuration allows for large lateral excursions that are unattainable using conventional ROVs. Planned elimination of the fiber optic link over the next few years will provide autonomy to the design but will likely increase costs and complexity.

The DOLPHIN 3K is an excellent undersea research platform and is a valuable supplement or, in some cases, replacement to manned submersible operations. With a depth rating of over 3,000 meters combined with sampling capability, excellent video, CTD, and sonars, the DOLPHIN 3K has numerous salient features for undersea research applications. The newly developed Super-HARP low-light-level TV camera provided excellent color picture quality and high resolution under various lighting conditions. Superior visual acuity is an important criterion for unmanned platform science operations.

Figure 2. DOLPHIN 3K ROV.

A major advantage of the Super-HARP TV camera is the field of view, both width and depth, that the camera provides without a requirement for large separation of the camera and lighting to minimize backscatter. Prior to the development of this system, underwater TV cameras required high intensity lights that sometimes resulted in a narrow field of view and distracting backscatter from suspended particulate matter. Moreover, if a low-light-level camera is used, the resolution and picture quality are degraded. Immediate applications of the Super-HARP camera at JAMSTEC will be to map the hypothermal vent fields near the Okinawa Trough. In the past, it has been difficult to identify and navigate this complex field of "chimneys"; the Super-HARP camera will allow the detailed mapping of the seafloor macrostructure using the video images.

Beyond this initial application, the uses for the Super-HARP camera are virtually unlimited. The ability to see at greater distances, at a wide field of view, and at a suitably high resolution will aid all disciplines of undersea research conducted from unmanned and manned platforms.

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Mr. A.N. Kalvaitis is the senior engineer and operations director for the National Oceanic and Atmospheric Administration's (NOAA) National Undersea Research Program (NURP). As such, he is responsible for providing technical support and guidance on undersea platforms and ensures that NOAA's undersea research mission objectives and operations are technically feasible, safe, cost-effective, and efficient. He has also been a project engineer on an Ocean Thermal Energy Conversion (OTEC) program that conducted research and development on utilization of the ocean as a renewable power source. He received his B.S.M.E. from the University of Maine, Orono. Mr. Kalvaitis has published articles on undersea science platforms, OTEC developments, data quality assurance, and marine instrumentation. He is a member of the Marine Technology Society's Undersea Vehicles/ROV Committee and the Current Measurement Technology Committee of the Institute of Electrical and Electronics Engineers (IEEE). In addition, he is a member of the Engineering Committee on Oceanic Resources (ECOR) Working Group on Marine Resources.

Gregory Stone is a biological scientist and the Japan Program Manager for the NOAA National Undersea Research Program. He spent 2 years at the Japan Marine Science and Technology Center (JAMSTEC) as a visiting scientist in the deep sea research department. He is a member of the Science and Technology Agency (STA) Council for Advanced Technologies and was the fist non-Japanese to dive in the JAMSTEC SHINKAI 6500, currently the world's deepest diving submersible. Along with expertise in undersea technology, Stone is also a whale biologist with over 15 scientific publications. He received his bachelor's degree in ecology from College of the Atlantic and his master's degree in marine policy from the University of Rhode Island. He received the John A. Knauss Marine Policy Fellowship, the U.S. National Science Foundation (NSF) and Japanese STA postdoctoral fellowship, and the Antarctic Service Medal from the Navy and NSF.

20TH U.S.-JAPAN JOINT MEETING: SEA BOTTOM SURVEYS PANEL

This meeting was held on 20-21 November 1991 at the Japan Hydrographic Department of the Maritime Safety Agency near the Ginza in Tokyo, Japan. The reports were divided into four groups: (1) activities of the U.S. panel, (2) activities of the Japanese panel, (3) technical reports on electronic charts, and (4) technical reports on multi-beam technology and techniques. The reports and discussions from this meeting demonstrate the close cooperation between the statutory seafloor mapping agencies of both countries and their commitment to incorporate the latest advances in electronics and satellite navigation to aid mariners and scientists alike.

by Pat Wilde

ACTIVITIES OF THE U.S. PANEL

Dr. W. Erich Frey of the Coast and Geodetic Survey (C&GS) (old name reinstated after 20 years as the National Ocean Survey) reported on "Hydrographic Surveys and Nautical Charting Activities." A major mission is to map the U.S. Exclusive Economic Zone (EEZ) at a contour interval of 250 meters. Since 1983 105,000 mi^2 have been surveyed. Three ships, the SURVEYOR, DISCOVERER, and MT MICHELL, have Sea Beam multi-beam systems. The WHITING uses the German HYDROCHART II system. Since October 1989, 32 1:100,000 scale multi-beam bathymetric maps have been published of a total of 58 maps compiled. In 1991 398 new chart editions were published. Eighty-five percent of the National Oceanic and Atmospheric Administration (NOAA) charts have been converted to the North American Datum 1983, which is considered equivalent to WGS 84. Special bathymetric charts for fishing, showing in addition bottom sediment type, bottom obstructions, cable/pipeline routes, and LORAN-C lattices, are being published. To date 41 such maps are available. With the U.S. adoption of metric bathymetry, the C&GS will eventually convert all its charts, using this opportunity to standardize and modernize them. The initial effort will be concentrated along the Atlantic Coast. For the computer age, the C&GS is participating in both the Electronic Chart Display and Information Systems (ECDIS) and Automated Nautical Charting System (ANCS) programs for the development of electronic and automated charting systems providing digitized charts (IHO SP-57 - DX-90 format) and related software.

The report on sea bottom survey activities of the U.S. National Geophysical Data Center (NGDC) was given by Dr. Michael S. Loughridge. In the past year 4.3 million digital records of underway geophysical surveys from 212 cruises covering 676,000 track miles were added to the Boulder Database. This included 540,000 miles of bathymetric, 287,000 miles of gravity, and 316,000 miles of magnetic data. Contributing institutions were the U.S. Geological Survey (47 cruises), Lamont-Doherty (35 new, 27 updated), Hawaii (26), Germany (26), Scripps (20), U.S.S.R. (11), Brazil (7), Texas A&M (5), Japan Oceanographic Data Center (JODC) (4), The Netherlands (4), Woods Hole (3), the U.S. Navy (2), and the University of Connecticut (1). Total digital holdings, thus, are now 30,400,000 MGD77 records covering 11,300,000 nautical miles from 3,082 cruises. Analog holdings are now 6,500,000 miles of which 5,200,000 miles are seismic reflection lines. The Index to Marine Geological Samples with over 300,000 records is available (GEODAS) for PC-compatible users in a select/retrieval program. A compact disc version of the marine mineral geochemical data of heavy minerals and manganese nodules information is planned for release in 1992. The Marine Geological Analog Data Files now contain over 150,000 samples. NGDC also has an archive of GEOSAT satellite altimeter data. The Worldwide Tsunami Database now includes 1,900 events since 2000 B.C. covering 16 regions. The data include

5,500 records and are held in dBASEIII format for PC-compatible retrieval. Marine-related CD-ROM discs are available for (1) Deep Sea Drilling Program (DSDP) data files (September 1991), (2) cumulative index to DSDP (August 1991), and (3) geophysics of North America. Planned releases of CD-ROMs include (1) Ocean Drilling Program (ODP) data similar to DSDP, (2) marine minerals, (3) underway geophysics: GEODAS, and (4) igneous petrology.

ACTIVITIES OF THE JAPANESE PANEL

Dr. Takemi Ishihara discussed the 1991 marine geology activities of the Geological Survey of Japan. The Geological Survey of Japan has four sections conducting marine research: marine geology, marine mineral resources, marine geophysics, and coastal sedimentation, chiefly using the R/V HAKUREI-MARU. The survey is in the midst of a 5-year mapping program: "Marine Geological Study of the Continental Margin of the Eastern Border of the Central Sea of Japan" (FY 1989-1993). Four cruises with 160 days of ship time have been used thus far. The program "Evaluation System for Metallic Deposits Associated with Submarine Hydrothermalism," using two cruises per year from 1984-1989 in the Western Pacific south of Japan's main islands in the Izu-Ogasawara (Bonin) Arc, Northern Mariana Arc, and the Okinawa Trough areas, is now complete and the results are being published in the *Bulletin of the Geological Survey of Japan*. In coastal areas, "Study on Long Range Prediction Model for the Change of Shallow Water Environment for Optimum Industrial Development" (FY 1988-1992) is a project in the vicinity of Tokyo Bay. There has been a shift in emphasis from marine minerals to projects involving global change. Three programs are current: (1) "Research on Coral Reef Capacity of Absorption for Increasing Atmospheric Carbon Dioxide" (FY 1989-1991); (2) "Change of Paleoenvironment of Coastal Areas Due to the Past Sea-Level Changes" (FY 1990-1991), focusing on the Okhotsk coast of Hokkaido investigating the hypsithermal event of 5,000 years BP (before present); and (3) "Study on Circulation of Carbon Dioxide in the Ocean" (FY 1990-1994), using 120 days per year ship time in the Northwest Pacific. The Japan-France Joint Project on the Rift System in the South Pacific (STARMER) (FY 1987-1991) is concluding. Diving surveys in the North Fiji Basin with the SHINKAI 6500 have just been concluded (November 1991), following up the discovery of hydrothermal vent deposits by the NAUTILE in 1989. Other diving projects in 1991, using both the SHINKAI 2000 and SHINKAI 6500, are being pursued in the Japanese EEZ south of the main islands.

Activities of the Host Agency

The activities of the Japan Hydrographic Department (JHD) of the Japan Maritime Safety Agency (JMSA) were summarized by Dr. Shoichi Oshima, the local U.S.-Japan Natural Resources (UJNR) chairman and director of the Planning Division of the Hydrographic Department. Major publication activities included the 120th Anniversary Commemoration Bathymetric Chart, "The Southern Seas of Nippon," at a scale of 1:2,500,000, and a new chart series, "Information Map Against Natural Disasters," to facilitate a rapid evacuation plan for areas like near Mt. Unzen that are susceptible to episodic volcanic eruptions. A new ship, the HAMASHIO, launched in March 1991, will be used for the surveys. Five sheets are planned by the end of 1995. The S/V MEIYO, launched in October 1990, did a rapid response survey of the newly active Mt. Unzen area in June 1991. The ship also surveyed Mikura Seamount in the Izu-Ogasawara (Bonin) Arc to identify any changes after the series of earthquakes under the seamount. The TAKUYO, with Sea Beam, and the TEN'YO, with HYDROCHART II, surveyed the Nankai Trough and identified several tectonic features related to the subducting Philippine Sea Plate. The TAKUYO, as part of the long-term study of the oceanic area south of the Japanese main islands, in 1990 surveyed the Oki-Daito Ridge and vicinity with a 5-nautical-mile grid spacing. The JHD is doing sea trials of electronic chart systems in cooperation with the Tokyo University of Mercantile Marine and equipment manufacturers. This test will be reported by Dr. Saburo Sunaga later in this article. Dr. Oshima also announced that a new vessel, the KAIYO, similar to the MEIYO (550 tons), is planned to be completed in the fall of 1993. The new ship will be designed for onboard data processing and will have the various sensors connected by a local area network (LAN). For FY 1990 the JHD completed 8 harbor surveys and 223 chart updating surveys. During the same time, they published 18 new charts and 53 new editions of previous charts.

Activity Report of the Japan Oceanographic Data Center

Dr. Osamu Yamada, director of the center, and from the Japan Hydrographic Department, presented the summary report. The center is the only "comprehensive" Japanese repository for oceanographic data, plus it's the center for UNESCO/IOC International Oceanographic Data and Information Exchange System (IODE) for files from WESPAC, IGOSS, and MARPOLMON. Digitized bathymetric data in the MGD77 format geophysical files are handled with the J-BIRD (JODC-Bathymetric Integrated Random Database) system. The data archive is available in the J-BIRD

catalogue published in 1990. The center maintains digital GEBCO 1:1,000,000 plotting sheets. All the data handling computers (both PC-compatibles and Macintoshes) are connected by LAN. For internal use in Japan, the center has instituted an electronic bulletin board/mail exchange system called JOIDES (JODC Oceanographic Information and Exchange Service) with no fees except local phone charges. The GEODAS data handling system of NGDC, mentioned above in Dr. Loughridge's report, has been ported into the JODC, where PC-compatibles are used instead of a VAX as a file server. GEODAS will be modified to accept multi-beam data.

ELECTRONIC CHART DEVELOPMENT AND EXPERIENCES

RADM Christian Andreasen of NOAA presented papers on "ECDIS (Electronic Chart Display and Information Systems) Test Bed Project" and "Automated Nautical Charting System II." The test bed project is an outgrowth of the development of digital charts combined with progress in computer hardware and display systems as well as cheap and accurate real-time satellite positioning. These advances permitted the potential for ships to be navigated directly by digital chart systems called ECDIS.

The International Maritime Organization (IMO) is now developing standards to regulate any viable ECDIS with respect to safety and thus to staffing requirements. The IMO provisional performance standards define ECDIS as "consisting of an onboard processor and chart displays, connected to an electronic positioning system, and optionally to the ship's radar." It is supplied with an electronic chart database that originates at government hydrographic offices, and these databases are maintained by means of automatic updates received from satellite or shore-based radio stations.

Before ECDIS standards can be adopted, a series of actual field trials are run to evaluate the proposed standards. Partial evaluations of the provisional standards have been completed in Europe with the North Sea Test Bed Project, the German SeaTrans Project, and The Netherlands Test Bed Project. The United States is pursuing an ECDIS test bed program coordinated by Woods Hole in conjunction with a joint government-industry group. The Intergraph Corporation has been awarded the contract for the hardware for the U.S. test. The tested system is expected to consist of (1) computer processor with 670 MB hard drive; (2) interactive input via keyboard or mouse; (3) Global Positioning System (GPS) receiver with differential operation; (4) LORAN-C receiver; (5) INMARSAT-C satellite receiver-transmitter for updating the electronic charts; (6) radar interface to overlay the standard radar image on the chart display; and (7) software capable of the following: "route planning, navigation calculations, chart selection, combined radar-chart display, track deviation alarms, route monitoring, chart updating, scale selection, vessel track recording, and back-up charts." The system will test the provisional standards that

(1) "It should be impossible to alter the contents of the electronic navigation chart onboard."

(2) The ECDIS database and display can automatically respond to official Notices to Mariners by radio or by manual insertion.

(3) Navigational safety shall be maintained in the event of failure of ECDIS.

(4) The ECDIS shall provide suitable warnings of malfunction so that the operator can take appropriate corrective measures.

U.S. trials of the ECDIS will be held, upon successful completion of acceptance tests in July 1992, in Valdez, Alaska; San Francisco, California; Long Beach, California; Buzzards Bay, Massachusetts; New York, New York; and Norfolk, Virginia. The first series of tests on a variety of vessels including a Coast Guard cutter, a commercial tanker, and a container ship is scheduled for completion in May 1993. A secondary objective of the trials is to demonstrate that ECDIS can reduce operating costs by maintaining minimum fuel consumption routes and watch-standers.

RADM Andreasen indicated that Japanese cooperation in the test bed effort would be valuable, particularly in providing digital charts of major harbors as well as cooperative efforts involving Japanese shipping companies, marine electronic firms, government agencies, and other groups with maritime interests.

Sea trials on 13 March 1991 of the electronic chart system tested by JHD were summarized by Dr. Saburo Sunaga of the department. The results of the test were as follows:

(1) Superimposition and register of the radar image and the electronic chart information on the display are still a problem.

(2) Symbol resolution and colors used need to be improved for easier identification.

(3) Landmarks displayed on the screen should be limited to "conspicuous ones" to avoid clutter on the display.

Mr. Yorihisa Suwa, of Japan Radio, presented his company's integrated system called "Total NAVIGATOR III," which uses electronic charts to add coastal and channel navigation to its navigation system. Displayed information includes:

- Navigational data - graphic coast line, depth, boundaries, dangerous zones, markers, scheduled route, ship track, other ship's track from automatic radar plotting aids (ARPA)
- Numeric data - time, ship's position, speed, total distance, course to steer, bearing and time to way point, cross track error, from meters-heading, rudder angle, turn rate
- Weather data - wind direction and velocity, atmospheric pressure, relative humidity, air temperature, water temperature
- Hull motions - pitch, roll, metacentric height (GM), draft and trim, propeller slip ratio
- Engine data - propeller revolutions, propeller pitch, shaft horsepower, torque, main engine (M/E) loading, turbocharger revolution, M/E start air pressure, M/E temperature

The system allows the user to make an electronic chart from a paper chart, incorporating a computer with a digitizer. One electronic chart may have five mark (buoys, etc.) and seven line (coast line, depth contours, etc.) types at one time. One megabyte on a floppy disk holds a maximum of 15 electronic charts.

TECHNICAL REPORTS ON MULTI-BEAM TECHNOLOGY

Dr. Robert Tyce of the Ocean Mapping Development Center of the University of Rhode Island discussed "Opportunities for International Cooperation in Swath Sonar Processing." At this writing 82 swath bathymetry systems are being used world wide. The United States (29) and Japan (19) maintain the bulk of the systems, with Norway (8), Canada (5), U.S.S.R. (5), England (3), Germany (3), The Netherlands (3), France (2), Australia (1), India (1), Korea (1), and Spain (1). In the United States, recognizing the complex problems involved in integrating information from many different systems, the Defense Hydrographic Initiative was developed to deal with coordination among the Defense Mapping Agency, the Oceanographer of the Navy, and NOAA. The initiative treats three primary areas:

1. Standardization of hydrographic/bathymetric data collection, processing/evaluation, archiving and analysis/integration.
2. Product and service identification and definition and implementation of the necessary support process.
3. Coordination of research and development (R&D) initiatives among academia, private industry, allied hydrographic offices, and international organizations as appropriate.

Implied is the development of digital products such as a Master Seafloor Digital Database (MSDDB) to include: topographic properties, man-made points, line and area features, gravity, magnetics, geoacoustic properties, and acoustic bottom properties. Dr. Tyce proposes the creation of an International Working Group that would take the following actions:

- Create regional directories of organizations and individuals involved in swath sonar processing: Organization, Name, Computer Type, Address, Phone Numbers, and Computer Mail Address.
- Combine regional directories into an international directory.
- Conduct regional meetings of working groups with agency sponsorship.
- Conduct international meetings of representatives of regional working groups with sponsorship assistance from agencies and sonar manufacturers.
- Exchange processing software for swath bathymetry and imagery among working group members.
- Exchange swath sonar ship tracks and data through existing organizations.

Dr. Akira Asada, of JHD, presented a paper titled "New Bathymetric Surveying and Processing System Based on Sea Beam 2000." This was a discussion of the system on their new survey ship MEIYO, which begin surveying in March 1991. Navigation generally uses MX440GPS, MX4810GPS, and R-R LORAN-C in various order of priority depending on quality of the returns. This permits preparation of (1) a depth contour chart along the track, (2) a track chart, and (3) a sounding chart incorporating the navigation with the output of the Sea Beam system. JHD has modified the existing processing software and developed new programs to improve and extend the processing capability. Eventually they would like to have all processing in real time on ship board. The processing programs discussed in detail are as follows:

- Position-Fix Correction: This program is designed to remove spike errors in the fixes, to smooth meanderings produced by instability of the fixes, and to process differences in level that result from data from combinations of GPS satellites.

- JMSA Uniform Format: The use of this program converts the data from the multi-beam system to a unified system. Software is available for Sea Beam 2000, Sea Beam, HS-10, HS-200, and Hydrosweep.

- Erroneous Data Elimination: This program identifies and "corrects" spikes and anomalous readings based on integration of 100 shots looking fore and aft as well as right and left of the shot point, assuming that no topographic feature has only one spike datum. The program is designed to allow for complex topography near seamounts, scarps, trenches, etc. At present, processing of 100-shot points takes 18 seconds. One segment of a survey line, which corresponds to 150 MB, takes about a half day for processing.

- Contour Processing: This program translates the geographic positions to the longitude of the beam positions as the heading of the vessel usually differs from the direction on an X-Y chart. This leads to inaccurate cross track distances on a Mercator projection.

- Digital Color Printer Application: Programs written for the Pictography 2000 color thermal printer with a capacity of 2048x2560 pixels permit quality mesh map presentations of the processed soundings. With this software, three-dimensional image processing, magnitude mapping of sea bottom inclination, and direction mapping of sea bottom inclination can be produced in color coded mesh maps.

Other programs listed but not discussed include GPS Differential Postprocessing and Track Chart Processing. For the Sea Beam 2000 system programs include Contour Processing Time-Sequential, Sounding Chart, Root Mean Square (RMS) Error Calculation, Roll-Bias Assessment, Tidal Correction, Sound Velocity Path (SVP) Recalculation, and Sounding Accuracy Assessment. Dr. Asada pointed out that the Sea Beam system uses a mean speed of sound assumption. This would produce errors of just over 1% for depths shallower than 4,000 meters and worse than that at greater depths. He presented a series of examples showing how the Ray Curve, SVP, and Surface Layer Refraction corrections are influenced by the mean speed of sound assumption. Finally, examples were shown of the survey of the area of Mikura Seamount comparing real-time contour maps with postcruise processing (2 days). The real-time map is useful in identifying areas of poor sounding for resurvey before leaving the area. The combination of the existing Sea Beam 2000 system with the error check and correction software developed by JHD is providing extremely high quality bathymetric information with a low failure rate.

Continuing with the theme of error correction, Dr. Thomas Stepka of NOAA gave a paper on "An Automated Method of Detecting Errors in Beam Pointing Angles in Swath Sonar Arrays." The beam angle error is a function of the deviation about a ship's pitch, roll, and yaw axes. Conventionally, a "patch test" is run over a test area and the results are plotted by hand. However, the method requires a smooth bottom and is very labor intensive with marginal statistical significance due to the small number of points used. NOAA has awarded a contract to the TAU Corporation to develop an automated patch test analysis system. The system was delivered in August 1991. The algorithm developed (1) selects an initial estimate of pitch, roll, and yaw deviations and computes the depth for each model; (2) computes the sum of the squared differences between models at every sounding in the user-defined area (usually several hundred); (3) estimates new biases based on old estimates and partial derivatives of the model depth function; (4) computes new models based on new error angle estimates; and (5) continues iterations until the sum of squared differences ceases to decrease ("total number of iterations is usually 5 to 12"). Results to date indicate that the system can detect pitch and roll biases "accurately and repeatedly." Similar results for yaw have not been achieved, due to, for example, the ship's gyro input not sufficiently accurate and tests need to be run on steeper slopes.

"Sea Beam System of the Ocean Research Institute, University of Tokyo" was the paper given by Dr. Kensaku Tamaki. Sea Beam mapping cruises on the HAKUHO-MARU have been made to the Nankai Trough (1989), the Japan Trench (1990), and the Manus Basin (1991). Future cruises are planned for the Ayu Trough (1992), Kuril Trench (1992), and the Mid-Indian Ridge (1993). The presentation was mainly on the data handling systems. Data processing was managed by a four-channel serial (RS232-C, 9600 bps) interface inside a DG S/140 minicomputer. The real-time mapping system is operated by a Yokogawa-Hewlett-Packard 350 SRX workstation with 24 MB used for processing. Data from the Magnavox Series 5000 used for shipboard data (navigation, etc.) and from the Sea Beam system are stored in a 300-MB hard disk. All data files are accessible from shipboard workstations via an optic fiber cable Ethernet LAN. Formats and byte addresses for the various parameters are given in several detailed tables.

Dr. Katsutoki Matsumoto, of the Metal Mining Agency of Japan, presented for his colleagues Kouhei Maeda, Madao Saito, and Nobuyuki Murayama all of the Deep Ocean Resources Development Co. Ltd., a paper titled "Equipping R/V HAKUREI-MARU No. 2

with MBES and Test of MBES. MBES refers to Multi-Beam Echo Sounder, which was the Krupp-Atlas Hydrosweep. The HAKUREI-MARU is designed and equipped for exploration for mineral resources on the deep seabed. Thus the multi- and narrow-beam systems were tested with respect to their suitability for ocean mining surveys. For surveys deeper than 5,500 meters, the ship was modified to reduce underwater noise. Improvements were to install a high skew propeller and to add stern tunnel fins, auxiliaries, and pumps in the engine room and pipe lines were made vibration-proof in support. This reduced the noise level 12 dB at 12 knots and 26 dB at 8 knots. Tests in the spring of 1991 in the Izu-Ogasawara (Bonin) Trough of a 30-kHz narrow-beam echo sounder and the 15-kHz Atlas Hydrosweep showed good results in 9,000 meters thanks to the noise reduction procedures. In returning to port, the Hydrosweep system was used to survey the complicated sea bottom off the Boso Peninsula and was successful in producing a real-time seafloor contour map.

Dr. Norman Cherkis of the U.S. Naval Research Laboratory discussed "Multi-Beam Echo Sounding and SeaMARC II Acoustic Imaging in the Norwegian Sea." The R/V EWING, of the Lamont-Doherty Geological Observatory, during the summer of 1990 took about 22,000 km of track line over the Aegir Ridge in the North Atlantic. This cruise combined data from the Hydrosweep multi-beam echo sounder with the SeaMARC II acoustic imaging system. Data from the ongoing survey were transmitted by satellite back to land every third day, where backscatter analysis was done. This was done to determine the amount of acoustic energy absorbed by the sediment which, in turn, was used to model sedimentary features and infer processes, particularly in areas where there was no seismic profiling information. The photographically merged data from the two systems proved a successful way to interpret structural lineations and other fine-scale features.

Industry representative Mr. Hideharu Morimatsu of Furuno Electric Co., Ltd. presented "Development of Multiple Narrow Beam Echo Sounders for Shallower Waters." Two systems, the HS-200 II (150 kHz, maximum depth 600 meters) and the HS-500 II (500 kHz, maximum depth 50 meters), and the attendant software package "Sea Map PC" were discussed. The systems have been used in several practical situations including not only primary bathymetric surveying but in confirming locations of objects placed on the seafloor. In this example, an array of artificial fish shelters, each a 3-meter cube, was found not to be placed as planned. The area surveyed was 400 by 500 meters with an average depth of 130 meters varying about 5 meters. At 5 knots it took 200 seconds to survey with about 400 pulses emitted. Processing of the data for a bathymetric map, using their software with a conventional PC, is rapid. For a 40-minute survey and 4,440 transmissions, it took 22 minutes to initially process, 13 minutes to generate the grid, and 13 minutes to plot the chart on an X-Y plotter.

Mr. Shin Tani of JHD, substituting for Dr. Takeshi Matsumoto of the Japan Marine Science and Technology Center (JAMSTEC), showed a "Comparison of the Bathymetric Data of HS-10 Multi Narrow Beam Echo Sounder with Sea Beam Data." Two surveys of the Japan Trench at a depth below 6,000 meters, one by the R/V HAKUHO-MARU with a Sea Beam system in 1990 and the other by the M/S YOKOSUKA in 1991, were used to compare the systems. The chart produced from the HS-10 system plots about 50 meters deeper than that from the Sea Beam bathymetry. Small-scale features at such depth seem to be a problem for the HS-10 system, as apparent false features are generated as well as nonrecognition of established features. In general, short-wavelength topographic features clearly present in Sea Beam are reduced in the HS-10 reconstructions. Some of the differences may be explained by differences in the gate settings with cross track "noise" responsible for artifacts in the HS-10 system.

The final presentation was given by RADM Andreasen, substituting for CAPT John C. Albright of NOAA. The paper, "Use of Differential GPS at the National Ocean Service," described the efforts to develop and test a system for vessel positioning that improves the positions available for either the Standard Position Service (SPS) or the Precise Position Service (PPS) provided by the Global Position System (GPS). The differential system uses a static GPS receiver at a known location to determine the satellite range correction for each satellite as it passes by. These corrections are transmitted to the user for the position calculation at sea. The differential GPS (DGPS) corrections change slowly so that a transmission of one per 20 to 30 seconds is sufficient. The improved satellite range information results in a longer survey window and thus use of low angle satellite passes, which formerly were unacceptable. Initial tests of the technique were in Hawaiian waters using a commercial COMSAT earth station facility. The corrections were eventually sent to the Pacific Ocean Region (POR) satellite where they were received by the survey ship DISCOVERY. A 19-hour test of the system while the ship was docked showed an average agreement of 5.8 meters. A second test at about 175 nautical miles at sea, checked with Mini-Ranger lines of position, showed an average agreement of 7 meters. Technical problems with the transmission terminals and failure of the Pacific Ocean Region satellite produced a downtime of 50%. To avoid such non-DGPS related failures, a joint NOAA-U.S. Coast Guard system where

radio beacons are used promises to be useful to within 300 nautical miles of the coast line. The accuracy of this system is thought to be about 10 meters or 2 standard deviations. The radio beacon system was tested in July 1991 on the RUDE using the Montauk Point, New York beacon. Here the Mini-Ranger and the DGPS positions agreed to about 5 meters. Radio beacon systems are planned for operations in the Gulf of Mexico near Corpus Christi and near Freeport, Texas, and for Cape May, New Jersey, and Cape Henry, Virginia, as well as the Montauk Point beacon. In addition, a "fly-away" DGPS system is being tested. This system is composed of two GPS receivers and a VHF radio data link. The system was tested successfully in Lake Michigan on a 22-foot launch. It is considered that the DGPS systems either fixed or fly-away will become the primary positioning system for mapping, especially in near-shore areas of the EEZ.

Pat Wilde joined the staff of the Office of Naval Research Asian Office (ONRASIA) in July 1991 as a liaison scientist specializing in ocean sciences. He received his Ph.D. in geology from Harvard University in 1965. Since 1964, he has been affiliated with the University of California, Berkeley in a variety of positions and departments, including Chairman of Ocean Engineering from 1968 to 1975 and Head of the Marine Sciences Group at the Lawrence Berkeley Laboratory (1977-1982) and on the Berkeley campus (1982-1989). He joined ONRASIA after being the Humboldt Prize Winner in Residence at the Technical University of Berlin. Dr. Wilde's speciality is in paleo-oceanography and marine geochemistry, particularly in the Paleozoic and Anoxic environments. He maintains an interest in modern oceanography through his work on deep-sea fans, coastal and deep-sea sediment transport, and publication of oceanographic data sheets showing the bathymetry with attendant features off the West Coast of the United States, Hawaii, and Puerto Rico.

THE SCOOP ON ULTRASONIC MOTORS IN JAPAN

I was invited to Japan by Prof. Kenji Uchino of Sophia University (and more recently of Pennsylvania State) to give a talk at the Japanese Material Research Society's Solid State Actuator Symposium. My research in the Mobile Robot Group at the Massachusetts Institute of Technology (MIT) Artificial Intelligence Laboratory involves using ferroelectric thin films to make piezoelectric ultrasonic micromotors. This is a joint project with the Pennsylvania State University Materials Research Laboratory and the Lincoln Laboratory Solid State Division. This article describes my visit to Japan and what I learned of the state of the art in ultrasonic motors there.

by Anita Flynn

BACKGROUND

While we have been building robots for many years in our own group, one problem we face today is that while sensing and control for our robots can fit in small inexpensive packages, motors and batteries tend to be the largest, most costly items. Consequently, I am doing my Ph.D. research on ways to make very tiny, mass-produced robots and better actuators for micromachines. I am focusing on piezoelectric ultrasonic micromotors using ferroelectric thin films of PZT (lead zirconate titanate) in a joint project with the Pennsylvania State Materials Research Laboratory and Massachusetts Institute of Technology (MIT) Lincoln Laboratory. That is the reason I was invited to give the symposium talk at Kanagawa Science Park on 14 December 1991.

Piezoelectric ultrasonic motors are fairly new but widely popular in Japan, while almost unheard of in the United States. They were invented in 1981 in Japan by Toshi Sashida and there are now over 90 U.S. patents (all of Japanese authorship). The interesting part of my trip was that I was able to visit many companies that developed these motors, met the inventors, and learned of yet other newer companies that are incorporating these types of actuators into products. I visited Ricoh, NEC, Canon, and Panasonic. I also met many of the academic founders of the field at the conference and spent a day at Sophia University.

While my research focuses on using ferroelectric thin films to pattern ultrasonic micromotors (and minimotors) on silicon wafers, typically ultrasonic motors are macroscopic (1 to 3 inches in diameter) and formed from bulk ceramic PZT, on the order of 200 μm thick as compared to our 0.30-μm-thick films, which are made at Penn State in a sol-gel process. While ferroelectric thin films have been heavily supported by the Defense Advanced Research Projects Agency (DARPA) in the United States in the past few years for nonvolatile memories, our contribution has been to recognize that we can use sol-gel processed films to take advantage of their piezoelectric characteristics and actually pattern motors.

The idea behind a piezoelectric ultrasonic motor is to generate a traveling wave of bending in a metallic ring. The bending wave is excited by voltages applied to piezoelectric elements attached to the ring, and the excitation at the resonance frequency of the ring is typically in the ultrasonic range. A traveling wave in a beam causes a particle on the surface to generate elliptic motion. This forms the stator of the motor. A rotor or carriage pressed against the vibrating stator is then propelled along through frictional coupling.

Of course, other types of piezoelectric actuators have been around for years, such as multilayer stack actuators and inchworm motors for precision X-Y stages and hydrophone transducers for Navy sonar. The interesting thing about ultrasonic motors is that they deliver continuous macroscopic motion at inherently high torques and low speeds without the need for gears. Consequently, they can be made very thin and compact. They are also very quiet since there are no gears. In addition, they have quick response time and large holding torque even when

power is removed. Efficiency has reached 45% to this point.

With all that as background, let me relate what I learned of ultrasonic motors in Japan in my travels. Prof. Uchino works in the area of piezoelectric materials and actuators and has contact with many researchers in companies. He set up meetings for me at Ricoh, NEC, and Canon. I set up the meeting at Panasonic as we have collaborative work with them in the "Mobot" Laboratory.

RICOH

On 9 December we visited Ricoh Central Research and Development (R&D) Laboratories where approximately 350 people are employed. In their showroom of products we saw soon-to-be-introduced products in the areas of speech recognition boards for PCs, rewritable magneto-optical disks, conducting polymers for electronic displays, credit card thin batteries, and neural network chips for handwriting recognition. Then we heard talks by two researchers in the areas of micromachining and sol-gel PZT films for microactuators. The first talk described a parallelogram silicon electrostatic microactuator that had been a collaborative project between Ricoh, Prof. Fujita at the University of Tokyo, and visiting scientist Dr. Ken Gabriel, of AT&T Bell Laboratories and now of the Naval Research Laboratory (NRL), I believe. The second talk was by a young Japanese woman, a chemist, who was making thin film PZT using sol-gel processing. I was surprised that it was so similar to our work (their goal was also actuators, as opposed to memories, which is what most effort is focused on), but then the head of Ricoh R&D, Dr. Mario Onoe, had visited the Mobot Laboratory last year and also we had delivered papers on our work both at the Ultrasonics Symposium in Hawaii last December and the MEMS (Micro Electro Mechanical Systems) conference in Nara, Japan, last January. Still, I was surprised to see a company move so quickly! They didn't say specifically what their target application was, but generally they were investigating the area for possible uses in printheads.

NEC

We visited NEC Central R&D Laboratories on 10 December. NEC is a huge company, and over 1,600 people worked in that research facility. We also had two researchers there present their work to us. The first was on a new type of ultrasonic motor they had developed. (This work was presented at the 1989 Ultrasonics Symposium in Montreal). It was a spark plug shaped device that combined longitudinal and torsional vibrations to achieve elliptic motion and hence rotary output. They brought in a working prototype and demonstrated it for us. This motor can deliver high torque and they are working with Olympus to investigate possibilities for using it as the film-winding actuator in cameras. They have worked on this project for 4 years. They also have another flat, thin type ultrasonic motor for paper pushing in a very thin printer.

The second talk at NEC described their work in silicon micromechanics. I was surprised at how many different types of sensors and actuators they had fabricated. They started a few years ago, and their first project was a silicon pressure sensor with piezo resistors and temperature compensation circuitry. They had also made silicon accelerometers targeted for the automobile industry. More interestingly, they had made linear arrays of ultrasonic proximity sensors; a single-crystal, wafer-bonded, variable capacitance micromotor; a linear comb-type micromotor; and an electrostatic wobble motor that was fairly thick, about 30μm. Basically, they have duplicated just about every type of device that has been discussed in recent MEMS conferences.

Neither Ricoh nor NEC seemed to have a clear picture of where micromotors might lead them, but it was amazing to see the amount of resources applied to this realm (especially in light of the fact that Bell Laboratories has now discontinued all activity in the area, while they were the initial impetus for much of this field).

CANON

Our visit to Canon on 11 December was slightly different. This was not central research but rather the Lens Development Group, where they have developed and productized ultrasonic motors as the autofocus mechanism in their EOS series single-lens reflex (SLR) cameras. They produce 50,000 of these cameras each month and the motors are truly beautiful. Canon began work in 1983 and holds over one-third of the U.S. patents on these vibration wave motors.

Ring-type ultrasonic motors fit an autofocus application nicely because the motors are essentially hollow--perfect for passing wires through without a slip ring, or even for allowing light to be transmitted to the film from the lens. Since no gears are needed, the motor fits in the periphery of the lens barrel cylinder, and its quick response time and quiet sound make for an elegant camera. Also, it is interesting to note that one current problem with ultrasonic motors is that they tend to wear out because of friction and material fatigue. Consequently, an application such as fan motor might not be amenable, but autofocusing pictures is just fine.

Three engineers from the Canon group presented their work to us, gave us the specification sheets on three varieties of motors, and handed out copies of papers they had written. One talk explained the general fundamentals of the motor, one talk discussed how they overcame an early problem with squeal noise, and the third talk

nicely described finite element analysis of the rotor-stator slip-stick interaction. It was all quite impressive and they answered many questions I had formed after taking apart one of their motors back home and reading through their patents.

After the presentations, they walked us around their laboratories and showed us equipment they used in developing their motors, such as optical microscopes for measuring micron-scale deflections on the surface of the vibrating stators. Canon has 25 engineers working on ultrasonic motors. They also gave me some catalogs for the smallest electromagnetic motors commercially available today--Namiki motors, which are 7 mm in diameter. They mentioned that they had heard that Seiko-Densi had made a 10-mm ultrasonic motor, but they did not know any more details. I asked them about the Toshiba announcement of an electromagnetic motor, supposedly 1 mm in diameter, which had earned a two-paragraph article in the *New York Times* on 5 November, but they hadn't heard about it. The *Times* article gave few details.

SOLID STATE ACTUATOR SYMPOSIUM

The first day of the Solid State Actuator Symposium was 12 December. One speaker was Akio Kumada, who holds several patents on some very unique ultrasonic motors. He gave a talk on his latest, called a Revolving Center of Gravity Resonator, which vibrates radially, much like a hula hoop. His vision is to build a new generation of milliwatt motors that run from complementary metal oxide semiconductor (CMOS) chips and button batteries. He brought along an impressive working prototype that fit inside a watch face and rotated via an on-stator PC board and a 1.5-V lithium battery. His motor draws 15 mA. He has a small firm called Piezotech set up to sell the technology.

Dr. Kumada also had the information on the new Toshiba electromagnetic (EM) motor and the 10-mm Seiko ultrasonic motor:

Toshiba EM motor:

Dimensions ...... 3 mm diameter x 5 mm thick
No-load speed .. 200,000 rpm
Stall torque........ 10^{-5} Nm

Seiko ultrasonic motor:

Dimensions ...... 10 mm diameter x 5 mm thick
No-load speed .. 6,000 rpm
Stall torque........ 1 g f-cm

While at the conference, I talked to some young engineers at various car companies and found out that Toyota now has a ring-type ultrasonic motor in the headrest of the new Crown Majesta. The new top-of-the-line cars have over 60 actuators in the seats, mirrors, windows, antennas, etc. Nissan is also working on another, different type of ultrasonic motor. Essentially, the automotive companies are interested in these motors for their luxury cars because they are compact, very thin, and quiet.

On 13 December I gave my talk and showed videotapes of small ultrasonic stators patterned on silicon wafers that spun glass lenses 1.5 mm in diameter. Afterwards, a young engineer from Olympus that I was sitting next to said that he also was working on an ultrasonic micromotor. Prof. Tomikawa, from Yamagata University, who advises 20 students in this area, said he was affected by the talk and wanted to try to build a similar micromotor.

One person noticeably absent from the conference was Sashida, the original inventor of ultrasonic motors. Apparently, many companies now commercially producing ultrasonic motors have licensed the technology from him. He runs a small development company called Shinsei-Kogyo. One company they have licensed to, which manufactures and sells the motors, is Fukoko--a company that Toyota works closely with as a supplier of rubber for windshield wipers.

MATSUSHITA

I made a trip down to Osaka on 16 December and visited Central R&D at Matsushita Electric (Panasonic) and met with the ultrasonic motor group. At each company I visited, I gave my talk and explained our goal of building cheap, mass-producible small robots using ultrasonic motors. The group at Matsushita had been working on these motors for 8 years and showed me four or five working models: disk type, ring type, and linear models. They were extremely helpful and gave me insights from their experience to help me in designing better motors with higher output. They also offered to collaborate in the future and to answer any questions I might write to them about later.

Matsushita does not have any of their motors in products at the moment because they typically sell low-cost consumer electronics and the ceramic materials now are too expensive. For instance, one motor that they had built and which I saw spinning had the following specifications:

10-mm Matsushita ultrasonic motor:

No-load speed .... 900 rpm
Stall torque .... 25 g f-cm
Drive frequency .... 70 kHz
Drive voltage .... 60 V_{pp}
Drive current .... 5 mA_{pp}

Interestingly, the ceramic for this 10-mm motor would cost $1 (in lots of 1,000) and that was too large a sum for them!

I also learned much from the Matsushita group about the finer points of ultrasonic motor design, such as criteria for the teeth, or the mechanical amplifiers, and issues in control.

Separately from the ultrasonic motor work, Matsushita has another research group in Tokyo that is involved in the Ministry of International Trade and Industry's (MITI) large 5-year program in microrobotics. Matsushita is teamed with Mitsubishi and Murata to build small, pipe-crawling microrobots. They will be 10 mm or so in diameter and will be formed in modules and interconnected like a train. Sensors, such as ultrasonic imagers, will be actuated so that they can turn and inspect the walls of tubes.

SOPHIA UNIVERSITY

Finally, on 17 December, I spent the morning with Prof. Uchino at his laboratory at Sophia University. Four of his students presented their work to me on new high strain materials using antiferroelectric-ferroelectric phase switching, sputtered barium titanate thin films, fatigue analysis, and novel actuators such as "moonie" actuators, which incorporate the best features of both bimorph benders and multilayer stack actuators.

CONCLUDING REMARKS

All in all, it was a productive trip and I learned many things that will be helpful in designing our next generation of piezoelectric micromotors.

Anita Flynn received the B.S. and M.S. degrees in electrical engineering from the Massachusetts Institute of Technology, Cambridge, in 1983 and 1985, respectively. Subsequent to that, she spent 5 years as a research scientist at the MIT Artificial Intelligence Laboratory in the Mobile Robotics Group working on sensing and control problems in autonomous robots. Since 1990 she has been a Ph.D. student at the Artificial Intelligence Laboratory researching piezoelectric motors for miniature robots.

TELE-EXISTENCE WORK AT THE RESEARCH CENTER FOR ADVANCED SCIENCE AND TECHNOLOGY AT THE UNIVERSITY OF TOKYO

Tele-existence work at S. Tachi's University of Tokyo laboratory is described.

by David K. Kahaner

INTRODUCTION

In another article (see page 29) I described a paper by Prof. S. Tachi on tele-existence. His work seemed very interesting and I decided to visit and look in person.

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Prof. Tachi moved to the University of Tokyo several years ago from the Mechanical Engineering Laboratory (MEL) in Tsukuba. MEL is run by the Agency of Industrial Science and Technology (AIST), which is part of the Ministry of International Trade and Industry (MITI). About 10 years ago Tachi also spent a year at the Massachusetts Institute of Technology (MIT).

BACKGROUND

Tachi began our conversation by showing me a chart describing the different threads of research that are now converging to be part of what is currently called artificial (or virtual) reality (AR/VR). Below I have extracted the text and reorganized it to better fit in the format of this report. Looking backward it is fairly obvious that these projects shared many common elements, although it is doubtful if the researchers themselves thought in these terms.

- Virtual console (mouse, three-dimensional (3D) mouse, virtual window, etc.)
- Real time interactive 3D computer graphics (computer graphics (CG), 3D CG, etc.)
- Virtual products (computer-aided design (CAD), 3D CAD, interactive 3D CAD, etc.)
- Cybernetic interface (man-machine human interface, etc.)
- Responsive environment (3D video/holography and art, interactive video and art, etc.)
- Real time interactive computer simulation (computer simulation, real time computer simulation, etc.)
- Communication with a sensation of presence (telephone, teleconference, etc.)
- Tele-existence/telepresence (tele-operation, telerobotics, etc.)

Research into some of these topics began as early as the 1960s, for example, with Ivan Sutherland's computer graphics projects. The early 1980s saw rapid growth due to work by Furness, Kruger, Sheridan, and others. Currently in the United States, centers of excellence are at the University of Washington, MIT, and the University of North Carolina in the academic world; the National Aeronautics and Space Administration (NASA) and the Naval Ocean Systems Center (NOSC) within the U.S. Government; and at several small companies that are marketing products. (This list is meant to be suggestive, not exhaustive.)

Tachi's work was also mentioned in my *Scientific Information Bulletin* article on virtual reality ["Virtual reality," 16(4), 43-45 (1991)]. That report references a conference held July 1991 on

AR and tele-existence. The Proceedings of this conference has just appeared and is entirely in English, and I recommend it highly to anyone interested in getting a quick survey of the current research activities in Japan. Finally, note that a newsgroup, "sci.virtual-worlds," is operating. Tachi showed me the list of recent postings, and it is clear that this is a very active communication vehicle.

DISCUSSION OF THE VR ASPECTS OF THE JAPANESE ECONOMIC PLANNING AGENCY SURVEY

Last year, I electronically distributed a report I wrote summarizing a survey from the Japanese Economic Planning Agency (EPA) on technology through the year 2010 (see 2010.epa, 27 Sep 1991). VR was one of the topics discussed there. In the complete Japanese report more explanatory detail was presented. The EPA estimates that practical realization will be sometime around 2020 (this seems further downstream than I would estimate). EPA continues:

> Regarding the comparison of various countries' R&D [research and development] efforts at the present juncture in the VR field, both Japan and the U.S. are actively working on research and development of the system. At this particular point, however, the U.S. is more actively pursuing the system research. In the U.S., for instance, the aerospace industry's R&D projects and national-level projects in support of the industry are conducting truly large-scale simulations and are constructing excellent databases.
>
> Key technologies requiring breakthrough will be those used in development of 3D simulation models, supercomputer application technology, and self-growth-database technology.
>
> One form of social constraint standing in the way of practical utilization of VR will be the effects of its possible application to transportation systems as a part of the social infrastructure [sic]. Moreover, it will be influenced by the general public's perception and value judgments regarding the system. Economic constraints will affect business' attempts to establish a market and to drive costs down. Moreover, the need for securing technical specialists in the software development field and the resultant shortage in R&D funds, as well as other difficulties involved in recruiting R&D personnel, must be dealt with.
>
> VR's market scale is estimated as reaching approximately the ¥1T level. Accompanying this market, there will be an increase in the number of related industrial firms' research labs to as many as 100. Software applications fields will be extensive, and a large number of R&D divisions will be pursuing product research and development targeted for various social strata.
>
> Positive impacts created by VR on the industrial economy will include the emergence of a new simulation industry (which probably will maintain supercomputers) and revitalization of computer software-houses, computer industries, entertainment industry, and the aerospace industry. The secondary effects will be experienced by the information industry, the general communication-related industry, the publishing industry, newspaper and magazine businesses, and by TV and radio broadcasting.
>
> Negative impacts will be felt by industries which have tended to hold on to hardware-oriented products.

VR WORK AT TACHI'S LABORATORY

The point of this article is not to summarize VR work generally but only to describe the specific directions being taken at one laboratory. Tachi uses the term "tele-existence" to denote the technology that enables a human to have a real sensation of being at another place and enabling him/her to interact with the remote environment. The latter can be real or artificial. This is clearly an extension of the sensation we have when we use a joystick to move around the figures in a video game. In the United States, the term is "telepresence."

Related to this is work to amplify human muscle power and sensing capability by using machines, while keeping human dexterity and the sensation of direct operation. This work stems at least from the 1960s with developments of exoskeletons that could be worn like a garment yet provide a safe but strong environment. Those projects were not successful; damage to the garment would endanger the wearer. Further, the technology at that time did not allow enough room for both the human and the equipment needed to control the skeleton.

Another idea was that of teleoperation or supervisory control. In this, a human master moves and a "slave" (robot) is synchronized. Tele-existence extends this notion, in that the human really should have the sensations that he/she is performing the functions of the slave. This occurs if the operator is provided with a very rich sensation of presence that the slave has acquired.

In Tachi's laboratory, the tele-existence master-slave system consists of a master system with visual and auditory presence sensation, a computer system for control, and an anthropomorphic slave robot mechanism with an arm having seven degrees of freedom and a locomotion mechanism (caterpillar track). The operator's head, right arm, right hand, and other motion such as feet are measured by a system attached to the master in real time. This information is sent to four MS-DOS computers (386 x 33 MHz with coprocessors), and each computer generates commands to the corresponding position of the slave. A servo controller governs the motion of the slave. A six-axis force sensor on the wrist joint of the slave measures the force and torque exerted on contact with an object, and this measured signal is fed back to the computer in charge of arm control via A-to-D converters. Force exerted at the hand when grasping an object is also measured by a force sensor installed on the link mechanism on the hand and fed back to the appropriate computer via another A-to-D converter. A stereo visual and auditory input system is mounted on the neck of the slave, and this is sent back to the master and displayed on a stereo display system in the helmet of the operator. Many of the characteristics of the robot are similar to that of a human, for example, the dimensions and arrangement of the degrees of freedom, the motion range of each degree of freedom, and the speed of movement, and motors are designed so that the appearance of the robot arm resembles a human's.

Measured master movements are also sent to a Silicon Graphics (SG) Iris workstation. This generates two shaded graphic images that are applied to the 3D display via superimposers. Measured pieces of information on the master's movement are used to change the viewing angle, distance to the object, and condition between the object and the hand in real time. The operator sees the 3D virtual environment in his/her view, which changes with movement. Interaction can be either with the real environment, which the robot observes, or with the virtual environment, which the computer generates.

There are many details of the system that are carefully explained in Tachi's papers dating back to the mid-1980s and need not be repeated here.

I wondered about the choice of computer systems. Tachi commented that he preferred DOS to Unix for the control computers because DOS made it easier to process real time interrupts. On the other hand, if workstation performance is high enough, interrupts can be handled in "virtually" real time. The SG is fast enough for the needed graphics as long as the operator does not move his/her head too rapidly. Clearly, workstation performance is an important consideration in real time computer graphics.

Tachi demonstrated the system by sitting on a special "barber chair," putting on the large helmet, and inserting his right arm into a movable sling containing a grasping device that approximates the robot's arm. His left arm held a joystick that controls locomotion, forward, back, right, left, and rotation of the robot. Once so configured he proceeded to make the robot stack a set of three small cubes.

I tried it next. The helmet is large and bulky but is equipped with a small fan so that there is good air circulation. It is also heavy but is carried on a link mechanism that cancels all gravitational forces, but not inertia, somewhat like wearing the helmet underwater. The color display (one for each eye) is composed of two 6-inch LCDs (720x240 pixels). Resolution is good, better than I expected, but not crystal clear. Tachi explained that humans obtain higher apparent resolution by moving their heads when looking at objects, and that the same effect works in the helmet. He also explained that the 3D view has the same spatial relation as by direct observation (this is one place where workstation performance is needed), and tuning of the system in this area is one of the things that Tachi and his colleagues have been working on for almost 10 years. Tachi claims that operators can use the system for several hours without tiring or nausea; I am not sure if I could last that long. Nevertheless, I was able, first try, to move the robot to within grasping distance of the table, lift the three small blocks, and stack them without dropping any. Training time, zero.

This is one of the most advanced experiments of its kind in Japan. Tachi's laboratory is very close to downtown Tokyo and would be easy to reach.

Please refer to the reports referenced above as well as the references below for further descriptions of this project.

- S. Tachi et al., "Tele-existence (I): Design and evaluation of a visual display with sensation of presence," in *Proceedings of RoManSy'84*, Udine, Italy, 26-29 June 1984.
- S. Tachi et al., "Tele-existence in real world and virtual world," in *ICAR'91* (Fifth International Conference on Advanced Robotics), 19-22 June 1991, Pisa, Italy.

JAPANESE RESEARCH IN INTELLIGENT AUTONOMOUS ROBOT CONTROL

During November 1991, this office supported Prof. Yutaka Kanayama, of the Naval Postgraduate School, to visit Japan and study and report on Japanese research in the area of intelligent autonomous robots. His article centers on a major international conference that he attended, Intelligent Robots and Systems (IROS), as well as several site visits.

by Yutaka Kanayama

INTRODUCTION

Robotics is one of the subareas of computer science in which Japan shows competence comparable to the United States. Three Intelligent Robots and Systems (IROS) workshops have already been held in Japan, and this year's workshop is the fourth one in this series.

The concept of autonomous robots, which has been attracting many researchers, has numerous applications, such as tasks in high performance manufacturing, in hazardous environments, in warfare, etc. The research in autonomous robotics presented at the workshop is summarized, as are visits to several universities and research laboratories with activities in robotics.

IROS WORKSHOP

The workshop was chaired by

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Despite its name, this was more like a conference than a workshop. The presentations given were from many countries including Japan, the United States, France, the United Kingdom, Italy, Germany, Korea, and China. We will focus on the following talks, which represent major activities in autonomous robotics in Japan. The page numbers refer to the *Proceedings of the IEEE/RSJ International Workshop on Intelligent Robots and Systems '91.*

"Estimating Location and Avoiding Collision Against Unknown Obstacle for the Mobile Robot Using Omnidirectional Image Sensor COPIS," Y. Yagi, Y. Nishizawa, and M. Yachida, Osaka University, pp 909-914. COPIS (COnic Projection Image Sensor) is an image sensor using a conic mirror that had already been proposed by the authors. Since this sensor is able to obtain a panoramic 360° view, it is straightforward to extract vertical edges in the robot's environment. This paper reports a method for estimating the location and the motion of the robot by detecting the azimuth of each object in the omnidirectional image. A method for matching azimuth orientations with a given environmental model is described. This research is led by

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"A Method of Indoor Mobile Robot Navigation by Using Fuzzy Control," S. Ishikawa, IBM Japan, Ltd., pp 1013-1018. This paper was presented by

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IBM Japan, Ltd.
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E-mail: isikawa@jjjpntscvm.bitnet

A sensor-based navigation method for an autonomous mobile robot using fuzzy control was presented. The purpose of using fuzzy logic was to construct expert knowledge for efficient and better piloting of the autonomous mobile robot. Its first task was motion tracking. An autonomous mobile robot senses positional and orientational errors from its planned path to decide the next incremental motion. The second task was

obstacle avoidance. The robot senses the size and shape of an open area ahead to avoid stationary and moving obstacles. Included in this system are 155 fuzzy rules. Although only simulation results are reported in this paper, a real robot's behavior was presented in the video tape demonstration. Fine tuning of the rule-based and membership functions is done on the simulator. Several simulation results on stationary and moving obstacles were presented.

"A Guide Dog Robot Harunobu-5: Following a Person," H. Mori and M. Sano, Yamanashi University, pp 397-402. There are 250,000 visually impaired people in Japan, one of the reasons for the development of the guide dog robot. The authors reported that the outdoor autonomous mobile robot Harunobu-5 was able to find a person 3 to 5 meters ahead and to follow him. The robot consists mainly of a mission planner, a digital map, an interactive navigator, and an image understanding system. An interesting technical point in this research is the model of a pedestrian, which consists of several body parts successfully functioning in interpreting color images. The system contains an MC68030 (25 MHz) OS-9 system with color image memory (512*512), two gyroscopes, two lap-top computers, and an MC68020 (16.7 MHz) system for the "follow-person" behavior. This project has been led by

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and Computer Science
Yamanashi University
Takeda-4, Kofu 400, Japan
Tel: +81-552-52-1111

"Vehicle Command System and Trajectory Control for Autonomous Mobile Robots," S. Iida and S. Yuta, University of Tsukuba, pp 212-217. This paper presents a motion command system called Spur for autonomous mobile robots. Essentially, this functional command system enables a user to describe a path that is a sequence of straight segments and circular arcs. It includes the experimental results of implementing the principle on the robot Yamabico. [Note: I founded and led this robotic research group at the University of Tsukuba until 1984. After I left the university,

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who had been my assistant, has been continuing the project.

SITE VISITS

Shinko Electric Company

Shinko Electric Co. has been developing and producing commercial autonomous unmanned vehicles (AUVs) that are used in clean rooms for semiconductor manufacturers.

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is leading the development team. The autonomous mobile robot can plan a path and automatically navigate itself using ultrasonic sensors or magnetic tapes on the floor. It has a robot manipulator arm/hand to carry wafer cassettes among various equipment for semiconductor processes (see Figure 1). It is equipped with a charge coupled device (CCD) camera to obtain precise positioning. This company has been selling several vehicles to semiconductor manufacturers and is enhancing the current version to a more powerful one. Probably this is the most commercially successful unmanned vehicle in the world.

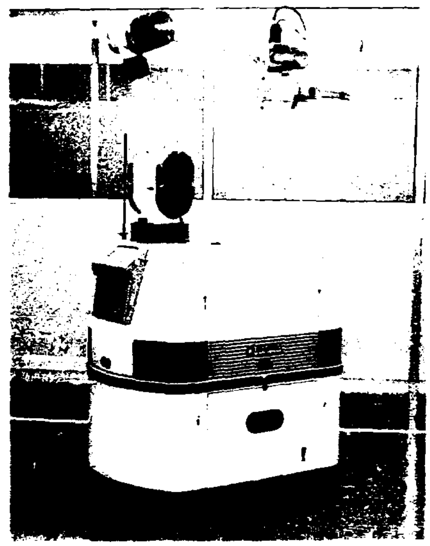

Figure 1. Shinko Electric Company Carry Ace robot (courtesy of Shinko Electric Co.).

Komatsu Ltd.

I visited

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Komatsu is one of the leading manufacturers of construction machinery. The main purpose of this visit was to see and discuss their seawater hydraulic actuator system, although this research itself is not the main topic of this report.

This is a part of the project for developing the "Total System of Advanced Subsea Robot," which is a part of the large-scale research and development (R&D) project titled "Advanced Robot Technology for the Hazardous Environment," supported by the Ministry of International Trade and Industry (MITI). The objective of the Subsea Robot project is to construct a robot that can guide itself, keeping its position and reference path in the presence of tidal current disturbance, and can do nondestructive testing and cleaning of man-made structures like oil rigs. At least the hardware development portions were successfully concluded in March 1991. This was a big national project and its component tasks were executed by numerous manufacturers including Komatsu. Also, Komatsu is developing and testing radio-controlled bulldozers, which will be upgraded to unmanned bulldozers. Electronics is eagerly introduced in their construction machinery.

Port and Harbor Research Institute

I am starting a joint research project, "Simulation and Control of Underwater Walking Robots," with this national institute. My partner is

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Port and Harbor Research Institute
Ministry of Transport
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This institute has three underwater walking robots named "Aquarobos" that were developed for inspecting the depth and evenness of underwater man-made rock beds. Each of them have six legs with three degrees-of-freedom each. At least one Aquarobo is perfectly successful in the practical task of inspection. These are probably the only practically working underwater walking robots in the world.

Nissan Motor Co., Ltd.

I saw

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at his laboratory. Currently, their main concern is man-machine interface in car driving. However, as one of their research activities, they have developed an autonomously controlled vehicle, Personal Vehicle System (PVS). This is equipped with sonar and TV cameras for external sensors. It is able to move smoothly along white lines (camera mode) or along guard rails (ultrasonic mode), avoiding obstacles on straight pathways, and is able to make turns at intersections. In the camera mode, the vehicle can travel at 60 km/h at straight path portions. Although the boundary conditions for the vehicle might be a little simpler than the ones for the experiments conducted in the Nav Lab at Carnegie Mellon University, the results by Nissan are also impressive in this state of the art.

Sogo Security Service Co., Ltd.

This company has been developing intelligent autonomous mobile robots for security guard services (see Figure 2), although it may still be a few years before they really introduce autonomous vehicles in their main tasks. Their autonomous robot has a map of indoor environment, a path planning ability, high-level smooth motion functions, fire and human detecting capabilities, and communication channels to the base computer system. The leader of this research group is

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Because of the difficulty in finding young workers for their tasks, the top administration is considering introducing the use of autonomous robots at least to assist human guards in some places. Problems at this moment are low behavioral stability and limited error recovery capabilities.

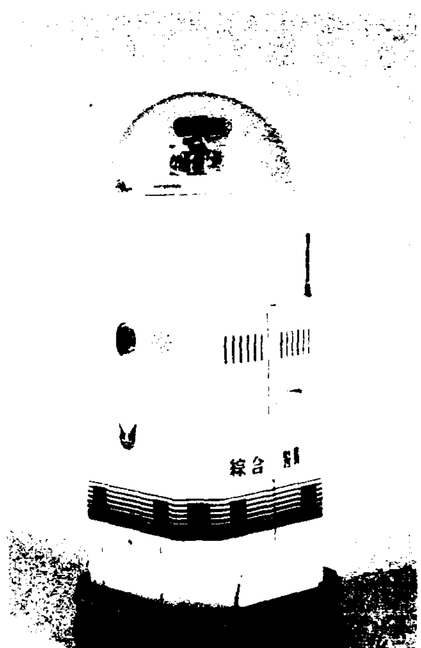

Figure 2. Security Guard robot (courtesy of Sogo Security Service Co., Ltd.).

IBM Japan, Tokyo Research Laboratory

I visited Mr. Shigeki Ishikawa at his laboratory in downtown Tokyo to watch his mobile robot, which is controlled by fuzzy rules (see Figure 3). The robot's hardware system was well designed and packaged nicely. It followed a reference path and, in the presence of obstacles, avoids them without failure. However, its behavior seemed to contain some unnecessary time-consuming motions compared with the behavior of other vehicles that are controlled by conventional analytical methods. In my opinion, the precision of the vehicle's motion is not good, either. [Since the author is adopting conventional geometry and control theory for controlling his own vehicle, his opinions might not be objective.]

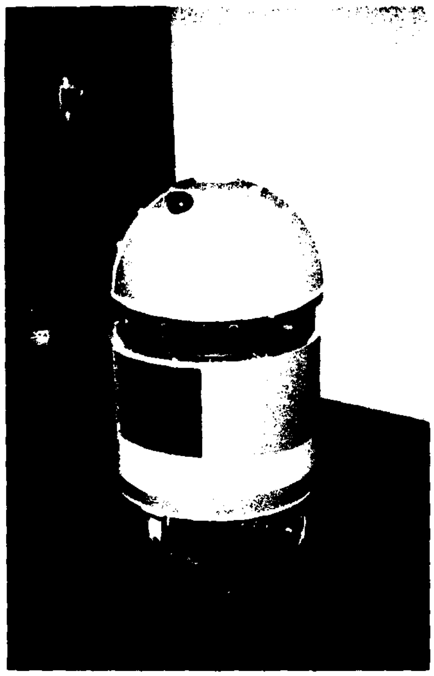

Figure 3. Mr. IB robot (courtesy of IBM, Japan).

Tokyo University, Department of Mechanical Engineering

I met

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in his laboratory to discuss his multiple mobile robots. He has been constructing four identical mobile robots to carry out tasks in a cooperative manner. An example of the tasks is to carry an object with more than one robot to a destination. Although the robots seem to be still in the system development stage and they look like toys, his imagination and originality might lead this project to a new frontier. He is conducting numerous other experimental autonomous robot projects including image understanding ones.

Japan Marine Science and Technology Center (JAMSTEC)

This is one of the most advanced research centers in marine science. I was interested in its underwater vehicle project and saw

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JAMSTEC is well known for its manned research submersibles SHINKAI 2000 and SHINKAI 6500, which are able to dive to the depth of 2,000 and 6,500 meters, respectively. JAMSTEC currently designing and constructing SHINKAI 11000, which will reach to the deepest sea bottom in the world. Dr. Hattori's group has been constructing and testing a flying saucer type autonomous underwater vehicle with six degrees-of-freedom (see Figure 4). The objective of the current project is to hover at a specified point using a light source that is placed on the sea bottom. A fuzzy control method is being used in this motion control problem. The saucer shape seems to make the hovering control mission easier as opposed to the conventional torpedo-shaped underwater vehicles.

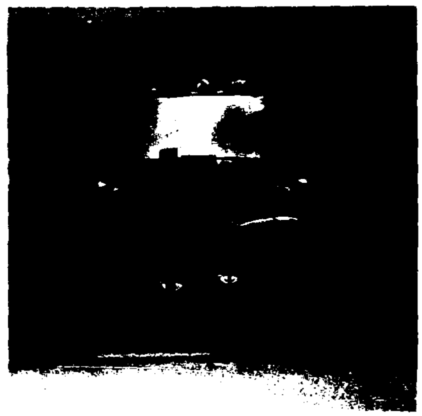

Figure 4. Autonomous underwater vehicle (courtesy of JAMSTEC).

ADDITIONAL INFORMATION

Let me mention two researchers who are active in autonomous robotics research, although my schedule did not permit me to visit their laboratories on this trip.

Prof. Shigeo Hirose
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is well known for his animal-type mobile robots. For instance, he has constructed quadruped walking robots that are able to climb staircases using tactile and/or image sensors. He has investigated a deep theory in gait control of walking robots. He has also constructed snake-type, wall-climbing, and ceiling-walking robots. Each of these mobile robots is the result of his incredible mechanical design abilities.

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has been developing the autonomous underwater vehicle PTEROA. PTEROA is able to dive to a depth of 2,000 meters and cruise for 1 hour. It saves energy loss by adopting an "under-water glider" type cruising mode. It dives using its own weight and, after it reaches to the deepest point, it disconnects its ballast to swim up to the sea surface. Ura is currently designing and constructing a functionally more powerful version of PTEROA.

Yutaka Kanayama received his B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Tokyo, Japan, in 1960, 1962, and 1965, respectively. He was a Professor in Computer Science at the University of Tsukuba from 1977-1984, where he worked in the field of theoretical computer science, artificial intelligence, and robotics. Since then he has been developing a family of autonomous mobile robots, "Yamabicos." He was with the Artificial Intelligence Laboratory, Department of Computer Science, Stanford University, from 1984-1986, where he joined the ALV research project. From 1986-1989 Prof. Kanayama directed the mobile robot project as Adjunct Professor in the Center for Robotic Systems in Microelectronics and in the Department of Computer Science at the University of California at Santa Barbara. In 1989 he joined the Department of Computer Science at the Naval Postgraduate School (NPS) in Monterey, California, as a professor. His current interests cover a wide spectrum from spatial reasoning theories to implementation of mobile vehicle systems. Prof. Kanayama is a member of the NPS Autonomous Underwater Vehicle project and is a principal investigator of the international joint project on the Autonomous Underwater Walking Robot with the Port and Harbor Research Institute in Japan.

NOTICE

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